

Searches for new physics under the LHC lamp post

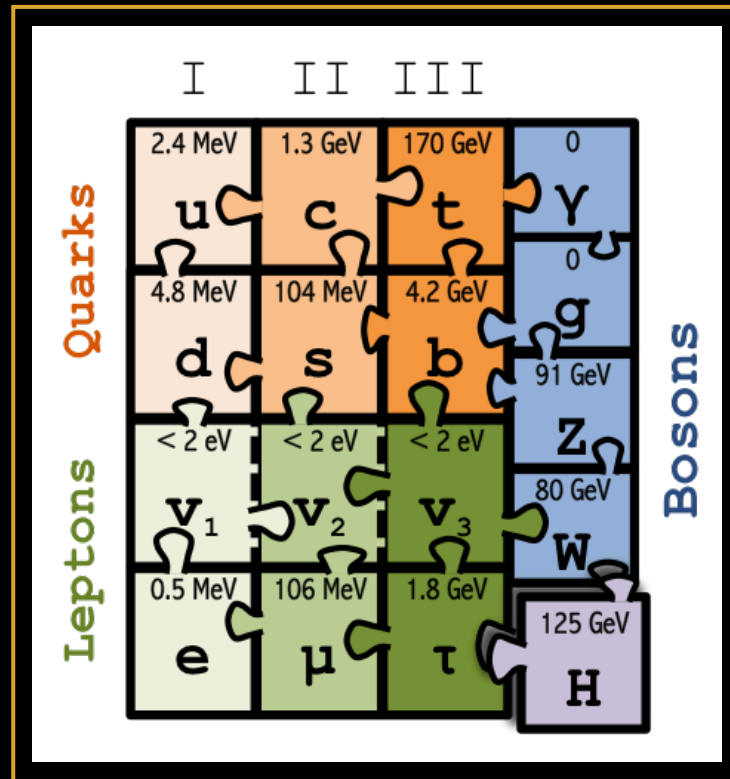
Anna Sfyrla

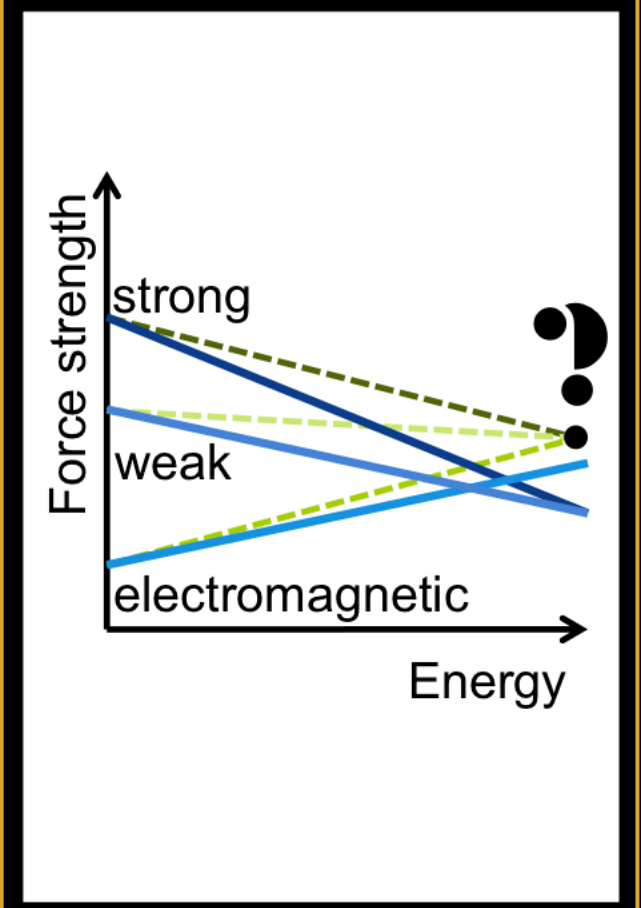
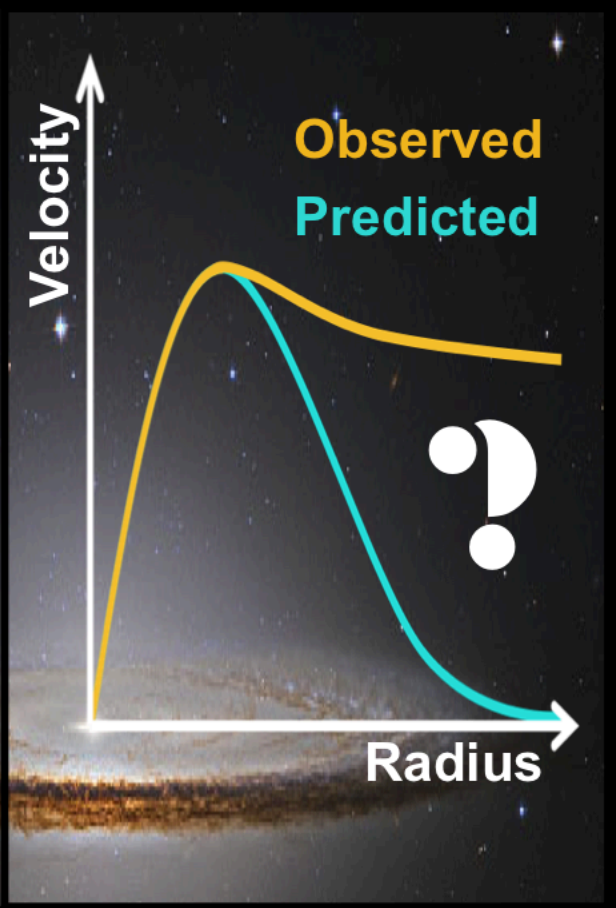
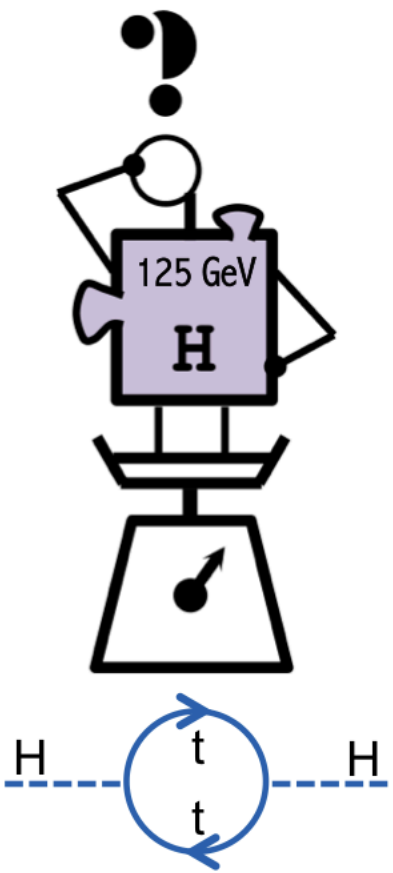
Collège des professeurs – 19/4/2021

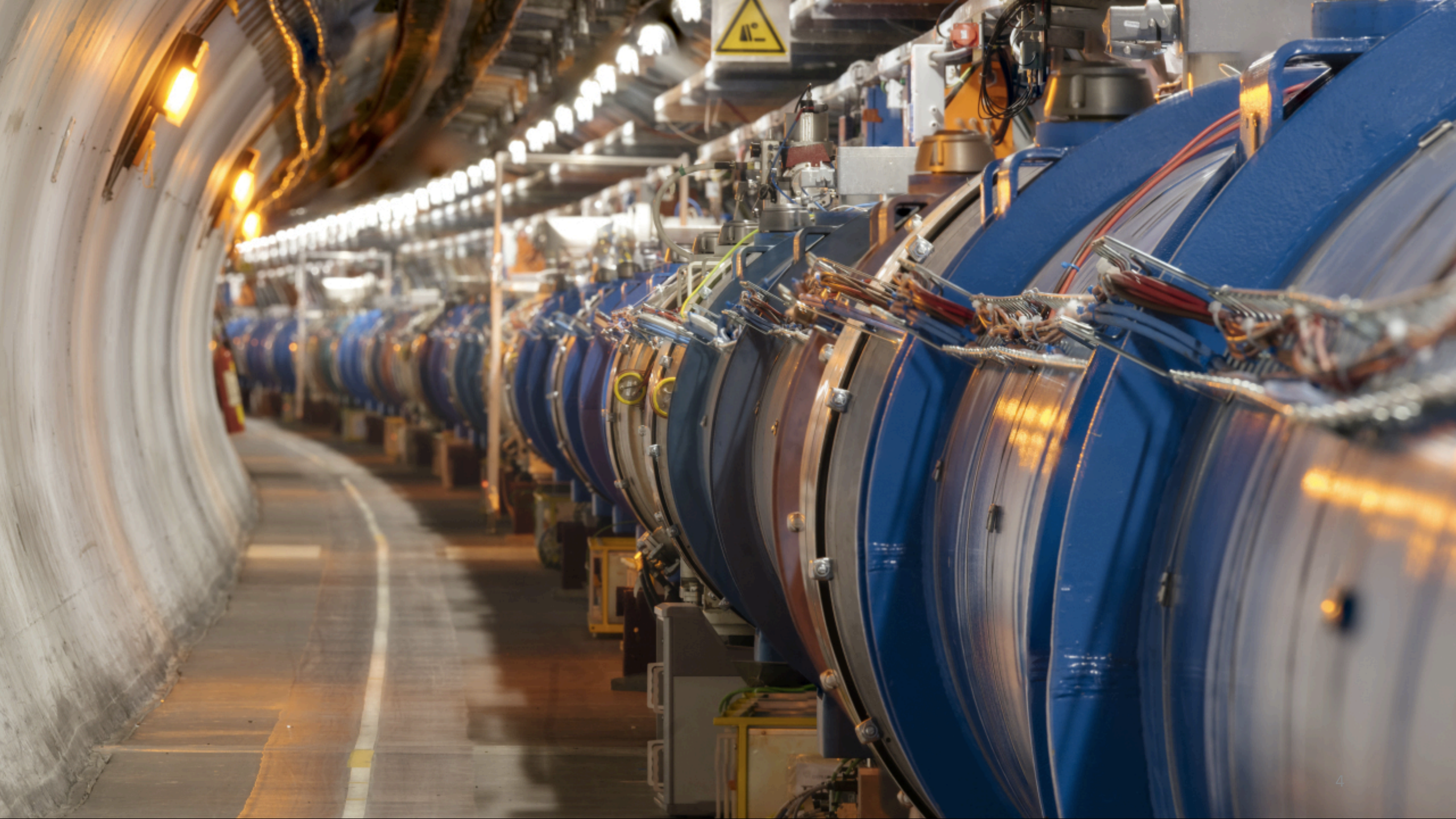
**UNIVERSITÉ
DE GENÈVE**

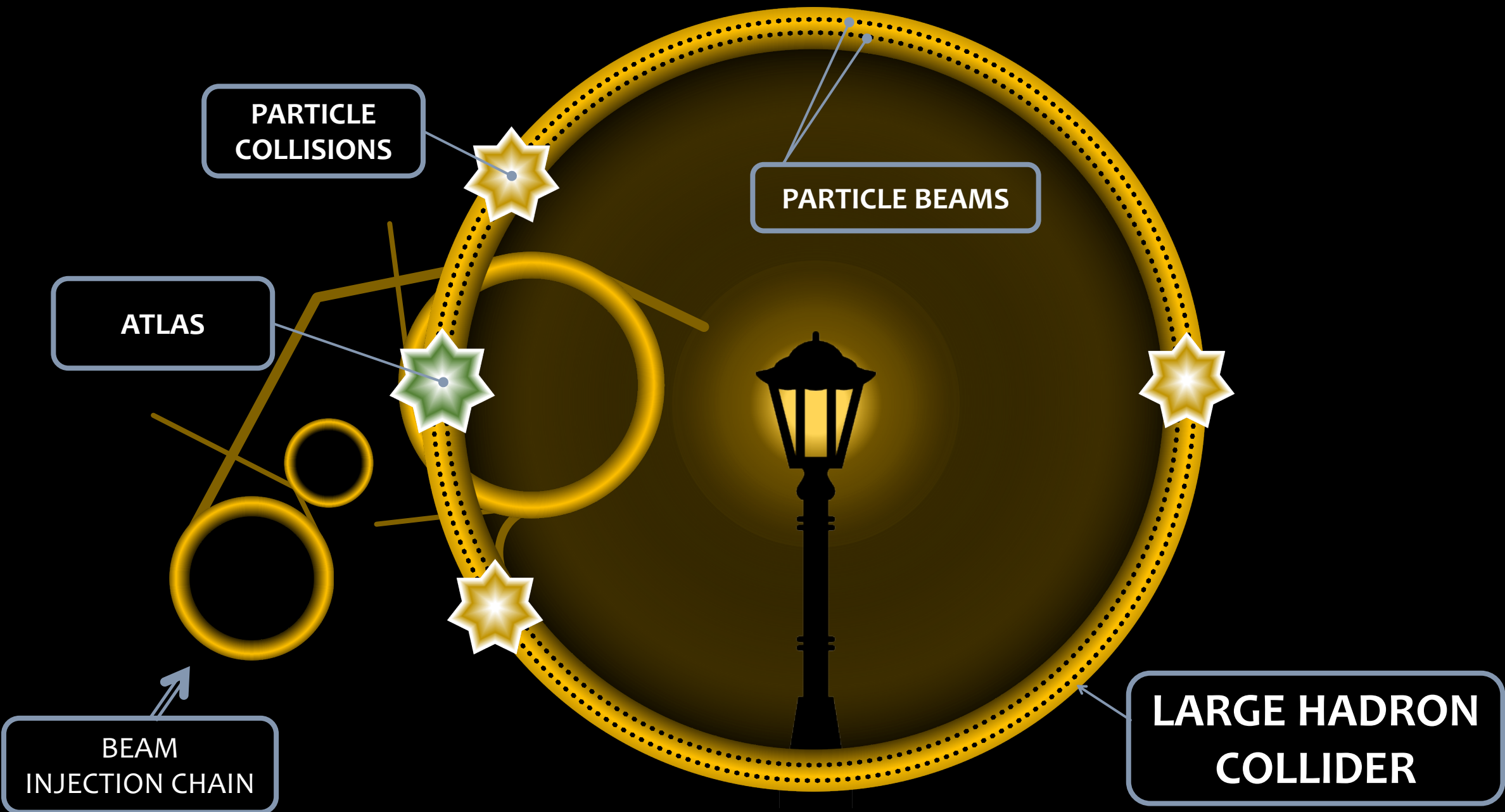
FACULTÉ DES SCIENCES
Département de physique
nucléaire et corpusculaire








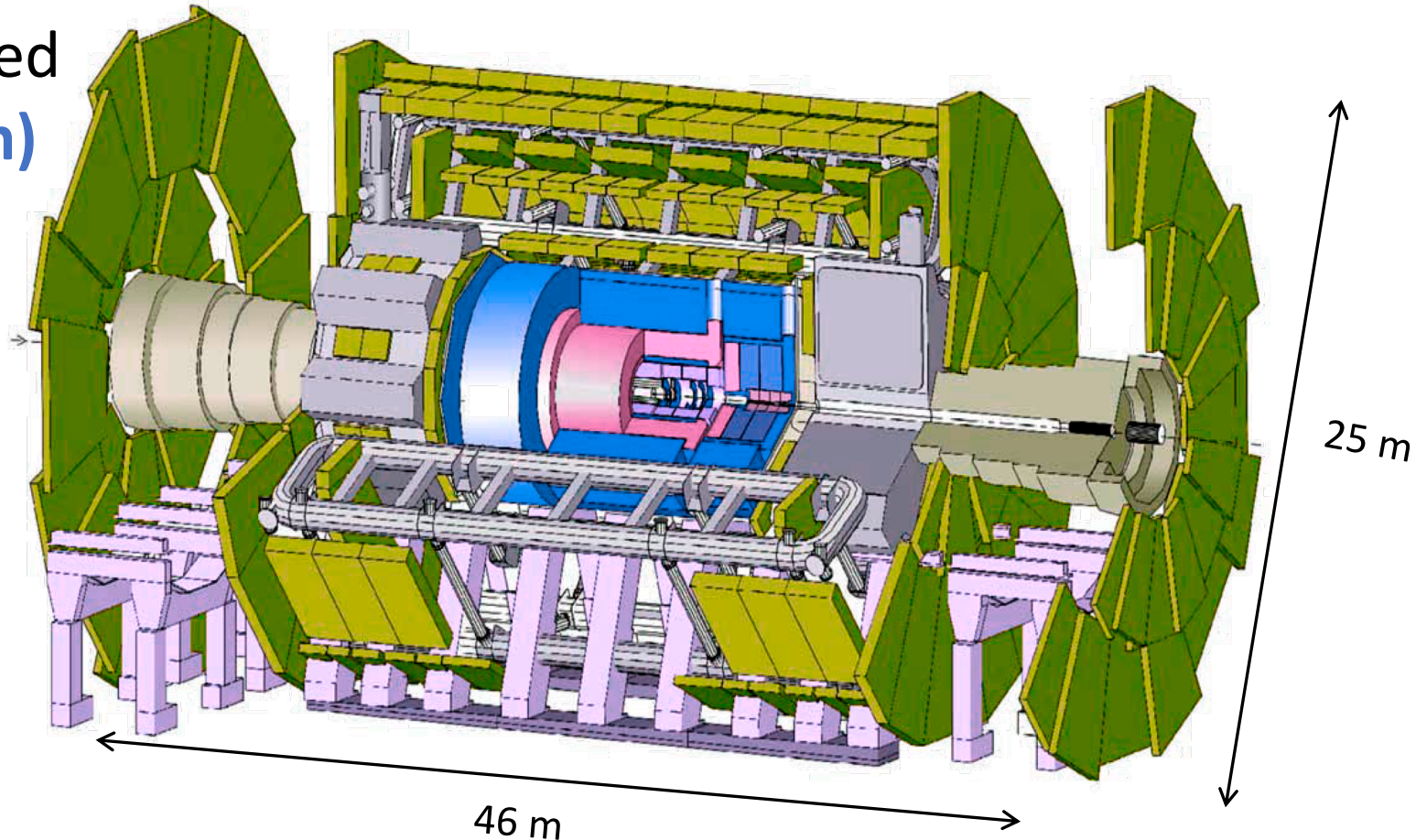




The ATLAS detector in numbers



- ✓ Weights **7 ktonnes** ()
- ✓ **2-4 T** superconducting magnets
- ✓ Position of particles recorded with an accuracy of **$O(10\mu\text{m})$**
- ✓ **100 M** channels
- ✓ **1 Giga** collisions/second
- ✓ **1000** events/second stored
- ✓ **500 PB** data on disk & tape
- ✓ **0.5 M** CPU cores used 24/7



The ATLAS Collaboration



3000

Scientific authors



38

Countries



180

Institutions



1200

Doctoral students



The ATLAS Collaboration



3000

Scientific authors



38

Countries



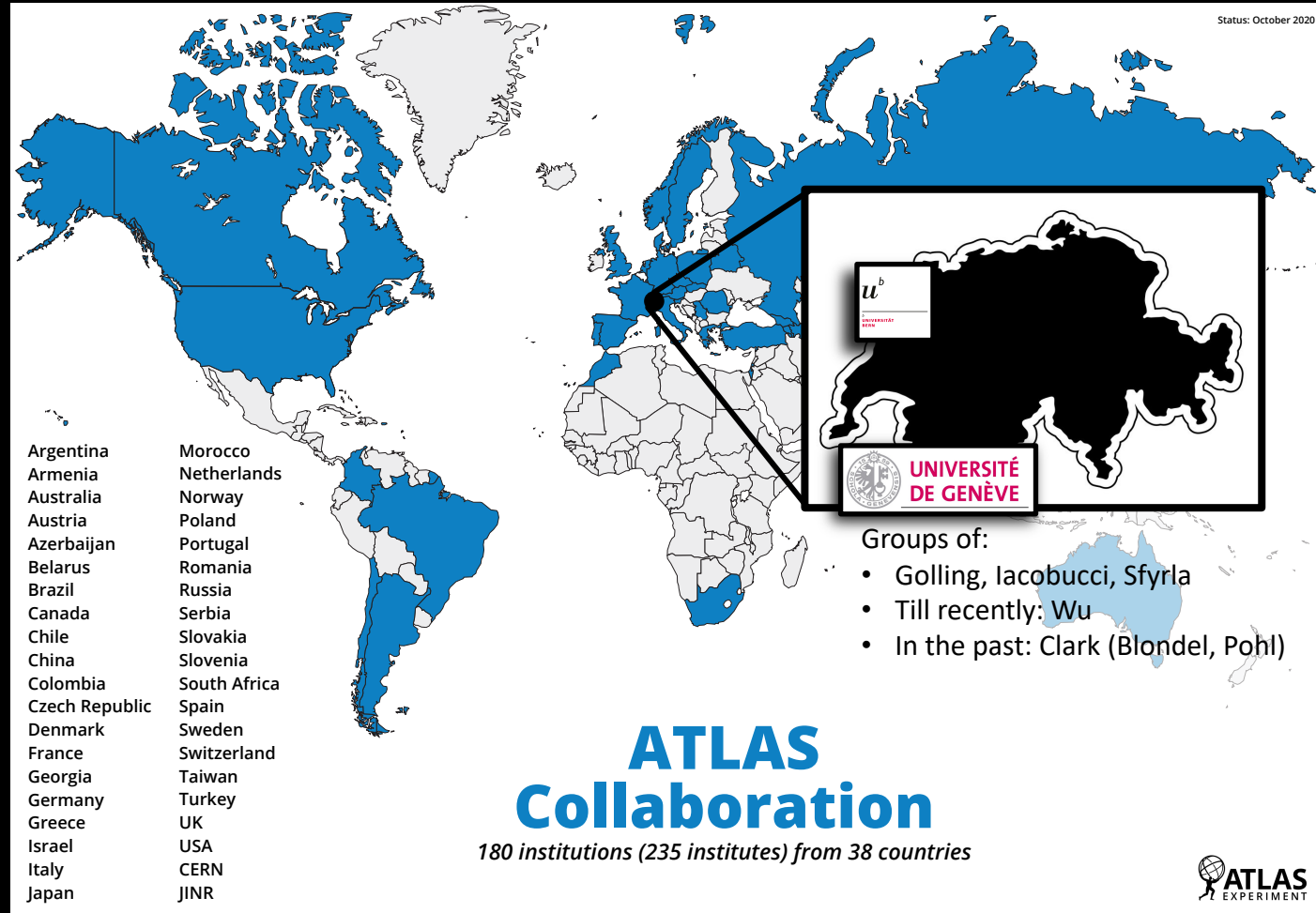
180

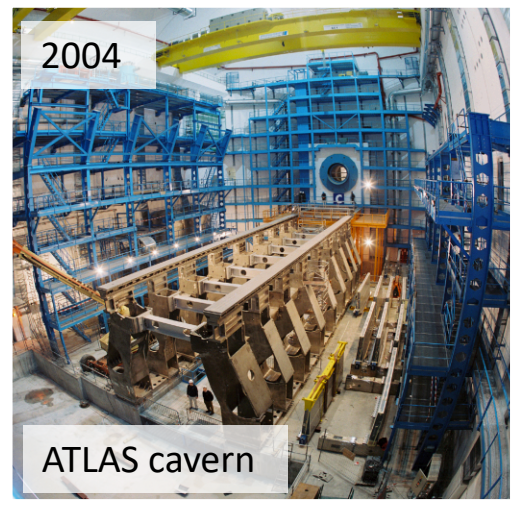
Institutions



1200

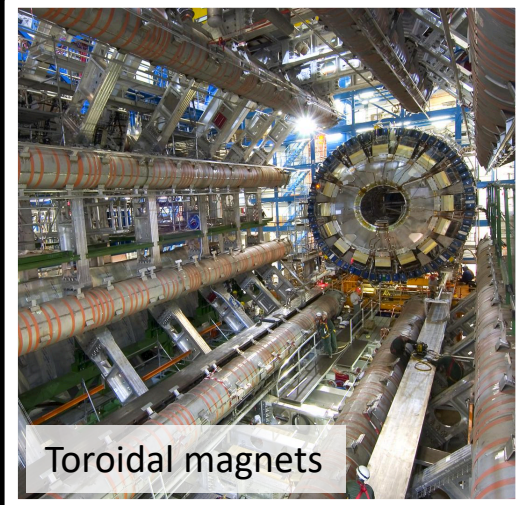
Doctoral students





2004

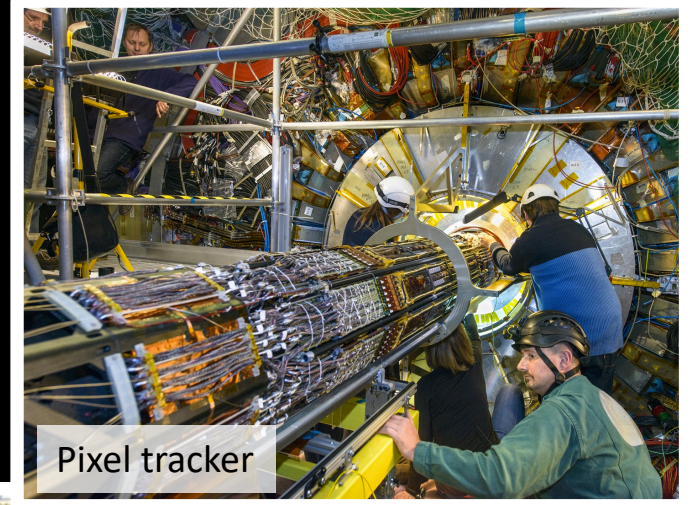
ATLAS cavern



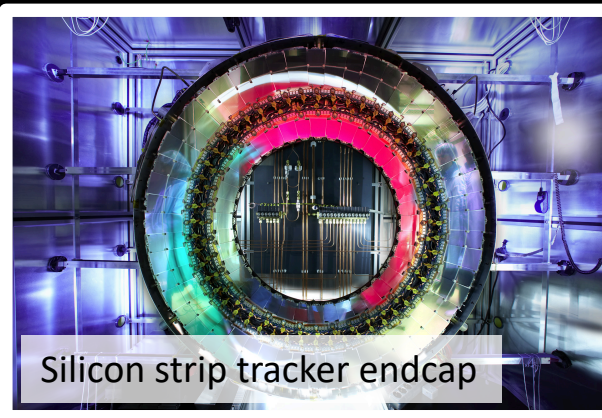
Toroidal magnets



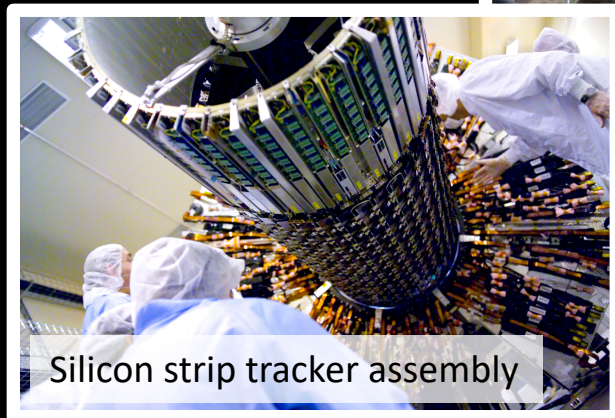
Calorimeter



Pixel tracker



Silicon strip tracker endcap



Silicon strip tracker assembly



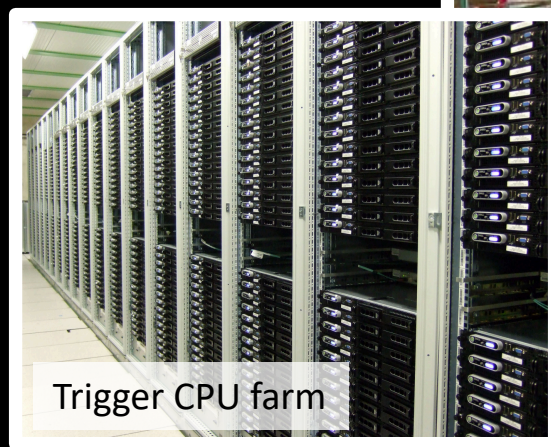
2006

Silicon strip tracker installation

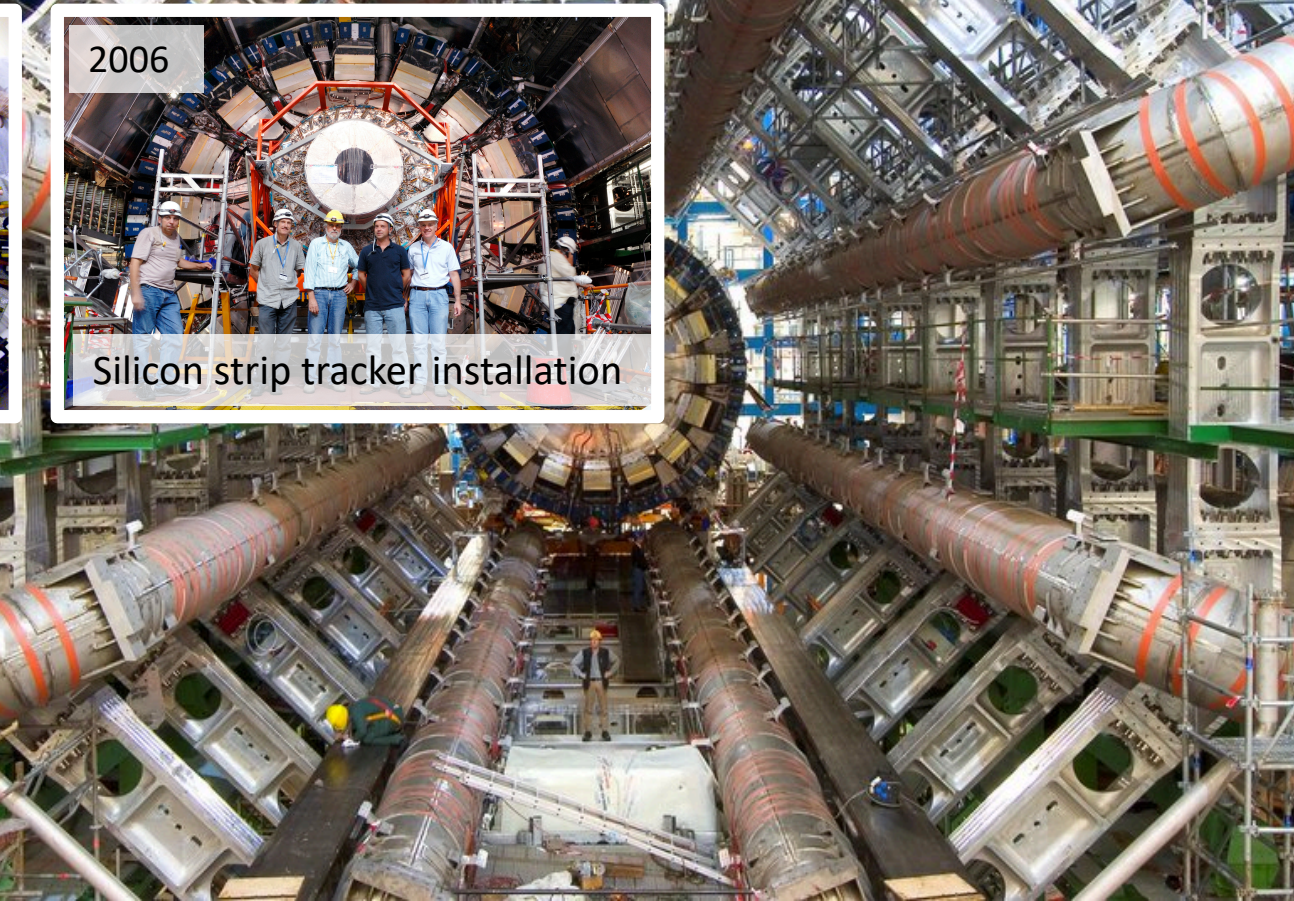


2014

Innermost pixel tracker installation



Trigger CPU farm





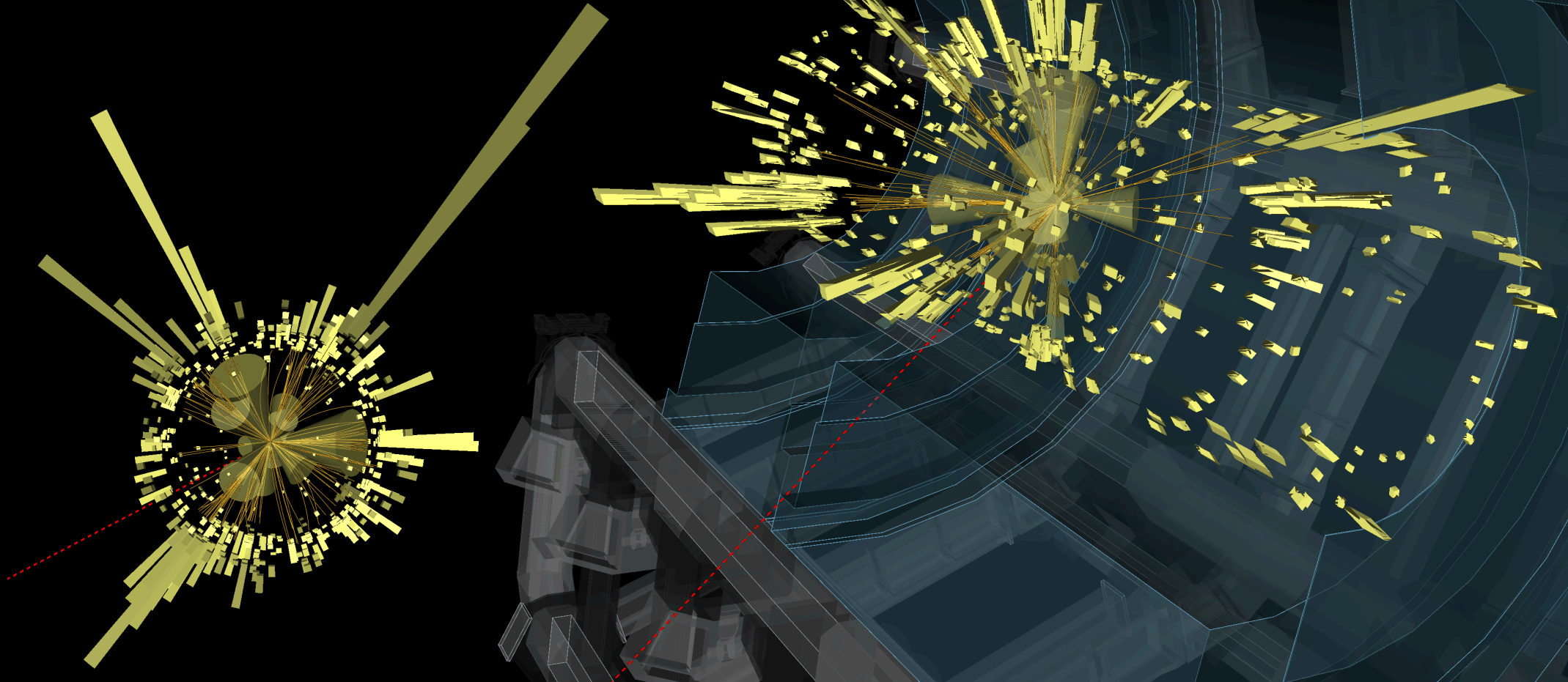
ATLAS

EXPERIMENT

Run: 355848

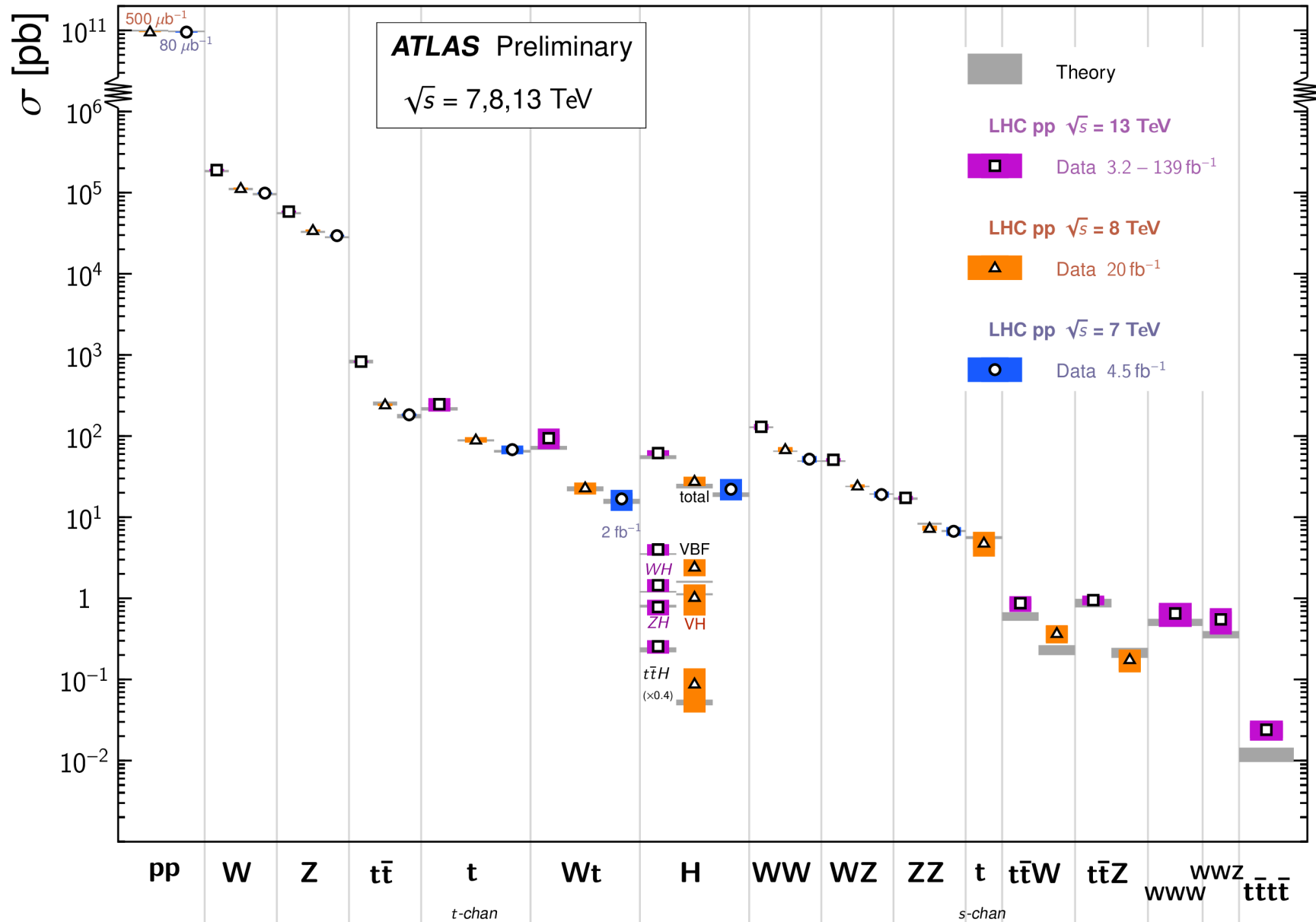
Event: 1343779629

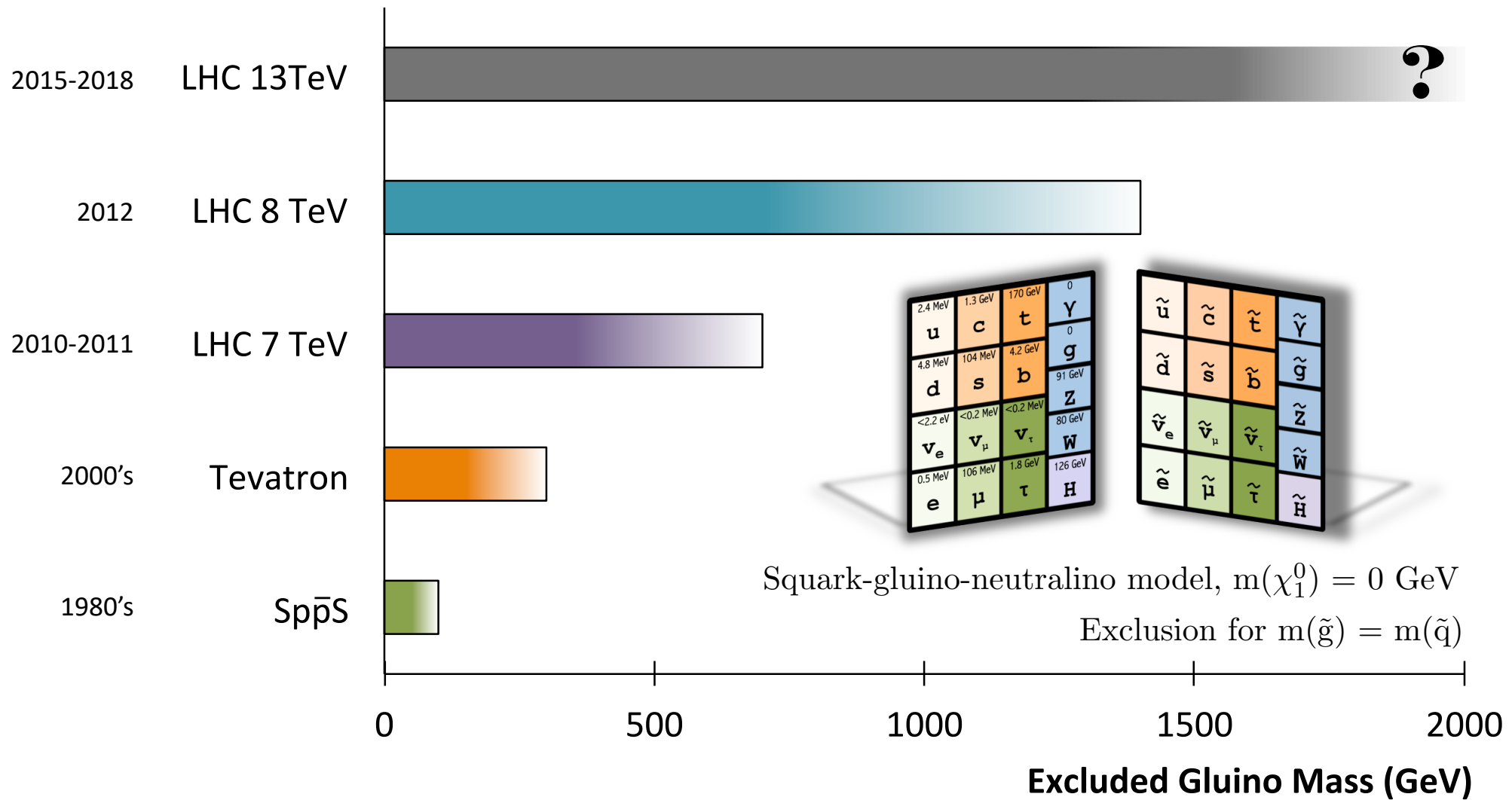
2018-07-18 03:14:03 CEST



Standard Model Total Production Cross Section Measurements

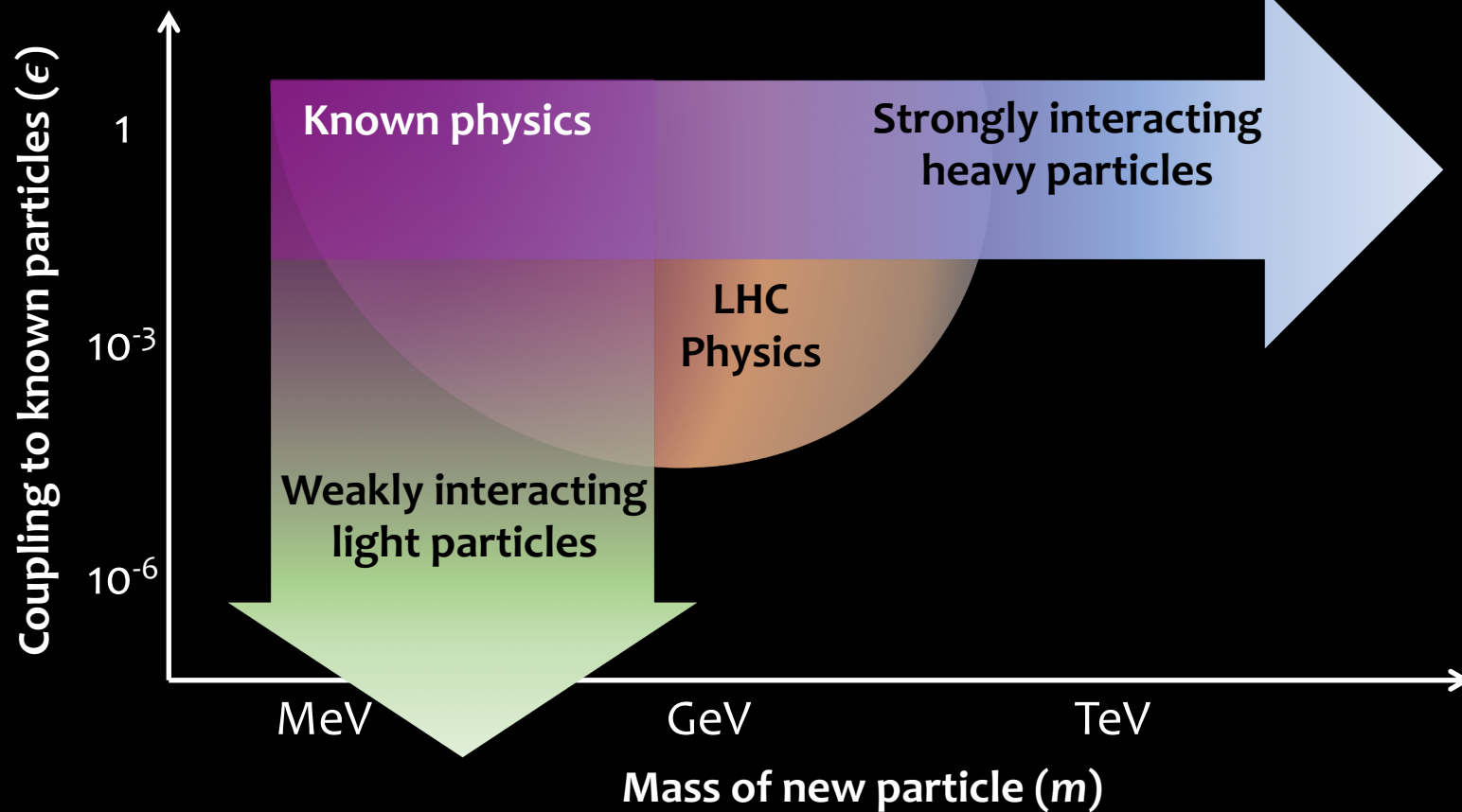
Status: March 2021





Model	Signature	$\int \mathcal{L} dt$ [fb ⁻¹]	Mass limit	Reference			
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	0 e, μ mono-jet	2-6 jets E_T^{miss}	139 36.1	\tilde{q} [1x, 8x Degen.] 1.0 1.85 \tilde{q} [8x Degen.] 0.9	$m(\tilde{\chi}_1^0) < 400$ GeV $m(\tilde{g}) - m(\tilde{\chi}_1^0) = 5$ GeV	2010.14293 2102.10874
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	0 e, μ	2-6 jets E_T^{miss}	139	\tilde{g} 2.3 \tilde{g} Forbidden 1.15-1.95	$m(\tilde{\chi}_1^0) = 0$ GeV $m(\tilde{\chi}_1^0) = 1000$ GeV	2010.14293 2010.14293
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}W\tilde{\chi}_1^0$	1 e, μ	2-6 jets	139	\tilde{g} 2.2	$m(\tilde{\chi}_1^0) < 600$ GeV	2101.01629
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$	2 jets E_T^{miss}	36.1	\tilde{g} 1.2	$m(\tilde{g}) - m(\tilde{\chi}_1^0) = 50$ GeV	1805.11381
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}WZ\tilde{\chi}_1^0$	0 e, μ	7-11 jets E_T^{miss}	139	\tilde{g} 1.97	$m(\tilde{\chi}_1^0) < 600$ GeV	2008.06032
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}WZ\tilde{\chi}_1^0$	SS e, μ	6 jets	139	\tilde{g} 1.15	$m(\tilde{g}) - m(\tilde{\chi}_1^0) = 200$ GeV	1909.08457
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0-1 e, μ SS e, μ	3 b 6 jets E_T^{miss}	79.8 139	\tilde{g} 2.25 \tilde{g} 1.25	$m(\tilde{\chi}_1^0) < 200$ GeV $m(\tilde{g}) - m(\tilde{\chi}_1^0) = 300$ GeV	ATLAS-CONF-2018-041 1909.08457
3 rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$	0 e, μ	2 b E_T^{miss}	139	\tilde{b}_1 1.255 \tilde{b}_1 0.68	$m(\tilde{\chi}_1^0) < 400$ GeV 10 GeV $< \Delta m(\tilde{b}_1, \tilde{\chi}_1^0) < 20$ GeV	2101.12527 2101.12527
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_2^0 \rightarrow b\tilde{h}\tilde{\chi}_1^0$	0 e, μ 2 τ	6 b 2 b E_T^{miss}	139 139	\tilde{b}_1 Forbidden \tilde{b}_1 0.13-0.85	$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130$ GeV, $m(\tilde{\chi}_1^0) = 100$ GeV $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130$ GeV, $m(\tilde{\chi}_1^0) = 0$ GeV	1908.03122 ATLAS-CONF-2020-031
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	0-1 e, μ	≥ 1 jet E_T^{miss}	139	\tilde{t}_1 1.25	$m(\tilde{\chi}_1^0) = 1$ GeV	2004.14060, 2012.03799
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	1 e, μ	3 jets/1 b E_T^{miss}	139	\tilde{t}_1 Forbidden 0.65	$m(\tilde{\chi}_1^0) = 500$ GeV	2012.03799
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 b\nu, \tilde{\tau}_1 \rightarrow \tau\tilde{G}$	1-2 τ	2 jets/1 b E_T^{miss}	139	\tilde{t}_1 Forbidden 1.4	$m(\tilde{\tau}_1) = 800$ GeV	ATLAS-CONF-2021-008
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	0 e, μ 0 e, μ	2 c mono-jet E_T^{miss}	36.1 139	\tilde{c} 0.85 \tilde{t}_1 0.55	$m(\tilde{\chi}_1^0) = 0$ GeV $m(\tilde{t}_1, \tilde{c}) - m(\tilde{\chi}_1^0) = 5$ GeV	1805.01649 2102.10874
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-2 e, μ	1-4 b E_T^{miss}	139	\tilde{t}_1 0.067-1.18	$m(\tilde{\chi}_2^0) = 500$ GeV	2006.05880
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	3 e, μ	1 b E_T^{miss}	139	\tilde{t}_2 Forbidden 0.86	$m(\tilde{\chi}_1^0) = 360$ GeV, $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) = 40$ GeV	2006.05880	
EW direct	$\tilde{\chi}_1^+\tilde{\chi}_2^0$ via WZ	3 e, μ $ee, \mu\mu$	≥ 1 jet E_T^{miss}	139 139	$\tilde{\chi}_1^+/\tilde{\chi}_2^0$ 0.64 $\tilde{\chi}_1^+/\tilde{\chi}_2^0$ 0.205	$m(\tilde{\chi}_1^0) = 0$ $m(\tilde{\chi}_1^+) - m(\tilde{\chi}_2^0) = 5$ GeV	ATLAS-CONF-2020-015 1911.12606
	$\tilde{\chi}_1^+\tilde{\chi}_1^+$ via WW	2 e, μ	E_T^{miss}	139	$\tilde{\chi}_1^+$ 0.42	$m(\tilde{\chi}_1^0) = 0$	1908.08215
	$\tilde{\chi}_1^+\tilde{\chi}_2^0$ via Wh	0-1 e, μ	2 $b/2 \gamma$ E_T^{miss}	139	$\tilde{\chi}_1^+/\tilde{\chi}_2^0$ Forbidden 0.74	$m(\tilde{\chi}_1^0) = 70$ GeV	2004.10894, 1909.09226
	$\tilde{\chi}_1^+\tilde{\chi}_1^+$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e, μ	E_T^{miss}	139	$\tilde{\chi}_1^+$ 1.0	$m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^+) + m(\tilde{\chi}_1^0))$	1908.08215
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0$	2 τ	E_T^{miss}	139	$\tilde{\tau}$ [$\tilde{\tau}_L, \tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39	$m(\tilde{\chi}_1^0) = 0$	1911.06660
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$	2 e, μ $ee, \mu\mu$	0 jets ≥ 1 jet E_T^{miss}	139 139	$\tilde{\ell}$ 0.7 $\tilde{\ell}$ 0.256	$m(\tilde{\chi}_1^0) = 0$ $m(\tilde{\ell}) - m(\tilde{\chi}_1^0) = 10$ GeV	1908.08215 1911.12606
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, μ 4 e, μ	$\geq 3 b$ 0 jets E_T^{miss}	36.1 139	\tilde{H} 0.13-0.23 0.29-0.88 \tilde{H} 0.55	$\text{BR}(\tilde{\chi}_1^0 \rightarrow h\tilde{G}) = 1$ $\text{BR}(\tilde{\chi}_1^+ \rightarrow Z\tilde{G}) = 1$	1806.04030 2103.11684
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet E_T^{miss}	139	$\tilde{\chi}_1^\pm$ 0.66 $\tilde{\chi}_1^\pm$ 0.21	Pure Wino Pure higgsino	ATLAS-CONF-2021-015 ATLAS-CONF-2021-015
	Stable \tilde{g} R-hadron	Multiple	Multiple	36.1	\tilde{g} 2.0		1902.01636, 1808.04095
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	Multiple	Multiple	36.1	\tilde{g} [$\tau(\tilde{g}) = 10$ ns, 0.2 ns] 2.05 2.4	$m(\tilde{\chi}_1^0) = 100$ GeV	1710.04901, 1808.04095
	$\tilde{\ell}\tilde{\ell}, \tilde{\ell} \rightarrow \ell\tilde{G}$	Displ. lep	E_T^{miss}	139	$\tilde{\ell}, \tilde{\mu}$ 0.7 $\tilde{\tau}$ 0.34	$\tau(\tilde{\ell}) = 0.1$ ns $\tau(\tilde{\ell}) = 0.1$ ns	2011.07812 2011.07812
RPV	$\tilde{\chi}_1^+\tilde{\chi}_1^+/\tilde{\chi}_1^0, \tilde{\chi}_1^+ \rightarrow Z\ell\ell\ell$	3 e, μ	E_T^{miss}	139	$\tilde{\chi}_1^+/\tilde{\chi}_1^0$ [BR(Z τ)=1, BR(Z e)=1] 0.625 1.05	Pure Wino	2011.10543
	$\tilde{\chi}_1^+\tilde{\chi}_1^+/\tilde{\chi}_1^0 \rightarrow WW/Z\ell\ell\nu\nu$	4 e, μ	0 jets E_T^{miss}	139	$\tilde{\chi}_1^+/\tilde{\chi}_1^0$ [$\lambda_{133} \neq 0, \lambda_{12k} \neq 0$] 0.95 1.55	$m(\tilde{\chi}_1^0) = 200$ GeV	2103.11684
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow q\tilde{q}\tilde{\chi}_1^0$	4-5 large- R jets	Multiple	36.1	\tilde{g} [$m(\tilde{\chi}_1^0) = 200$ GeV, 1100 GeV] 1.3 1.9	Large λ'_{12}	1804.03568
	$\tilde{u}, \tilde{t} \rightarrow t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow t\tilde{b}s$	Multiple	Multiple	36.1	\tilde{t} [$\lambda'_{233} = 2e-4, 1e-2$] 0.55 1.05	$m(\tilde{\chi}_1^0) = 200$ GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{u}, \tilde{t} \rightarrow b\tilde{\chi}_1^+, \tilde{\chi}_1^+ \rightarrow b\tilde{b}s$	$\geq 4b$	Multiple	139	\tilde{t} Forbidden 0.95	$m(\tilde{\chi}_1^+) = 500$ GeV	2010.01015
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow bs$	2 jets + 2 b	Multiple	36.7	\tilde{t}_1 [qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	2 e, μ 1 μ	2 b DV	36.1 136	\tilde{t}_1 0.4-1.45 \tilde{t}_1 [$1e-10 < \lambda'_{23k} < 1e-8, 3e-10 < \lambda'_{23k} < 3e-9$] 1.0 1.6	$\text{BR}(\tilde{t}_1 \rightarrow b\ell/b\mu) > 20\%$ $\text{BR}(\tilde{t}_1 \rightarrow q\mu) = 100\%, \cos\theta = 1$	1710.05544 2003.11956
$\tilde{\chi}_1^+/\tilde{\chi}_2^0/\tilde{\chi}_1^0, \tilde{\chi}_{1,2}^0 \rightarrow t\tilde{b}s, \tilde{\chi}_1^+ \rightarrow b\tilde{b}s$	1-2 e, μ	≥ 6 jets	139	$\tilde{\chi}_1^0$ 0.2-0.32	Pure higgsino	ATLAS-CONF-2021-007	

*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.



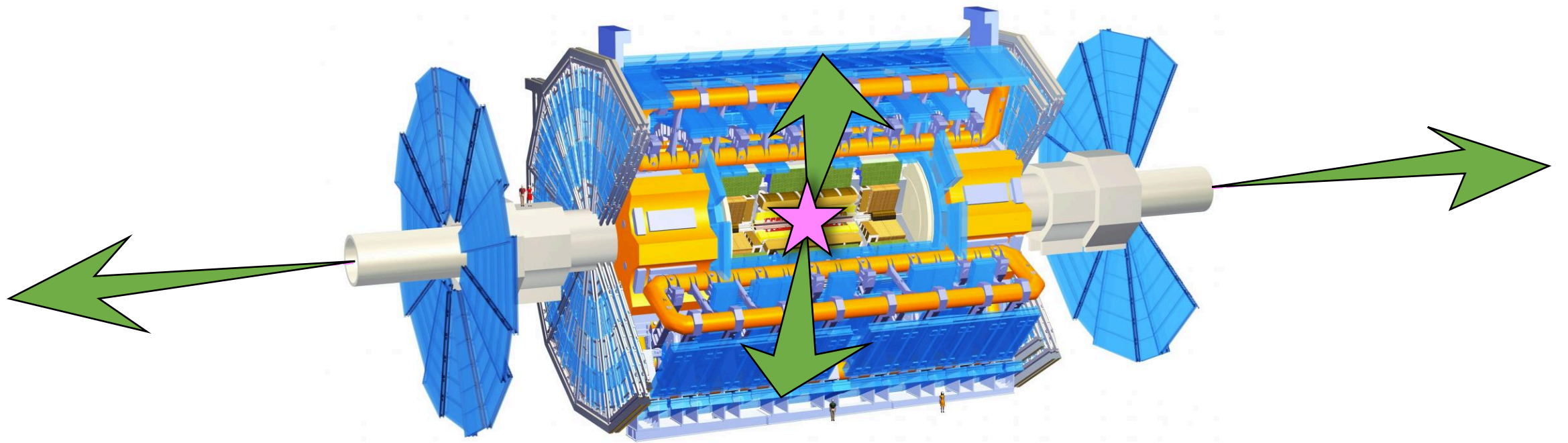
Improve instrumentation / experimental methods

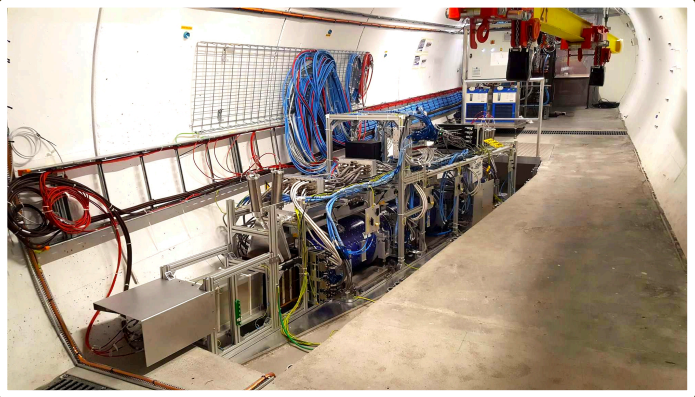
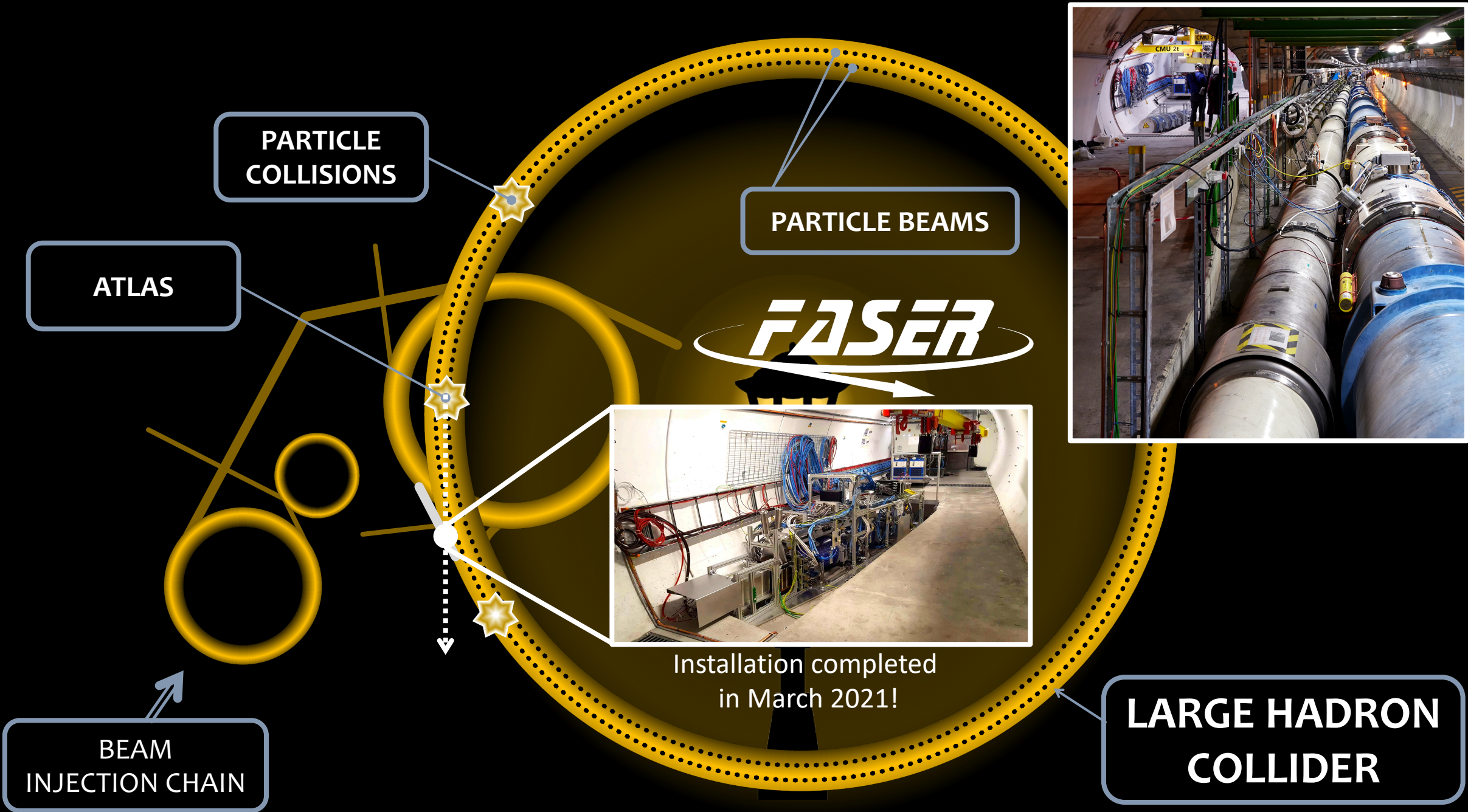


Get more data

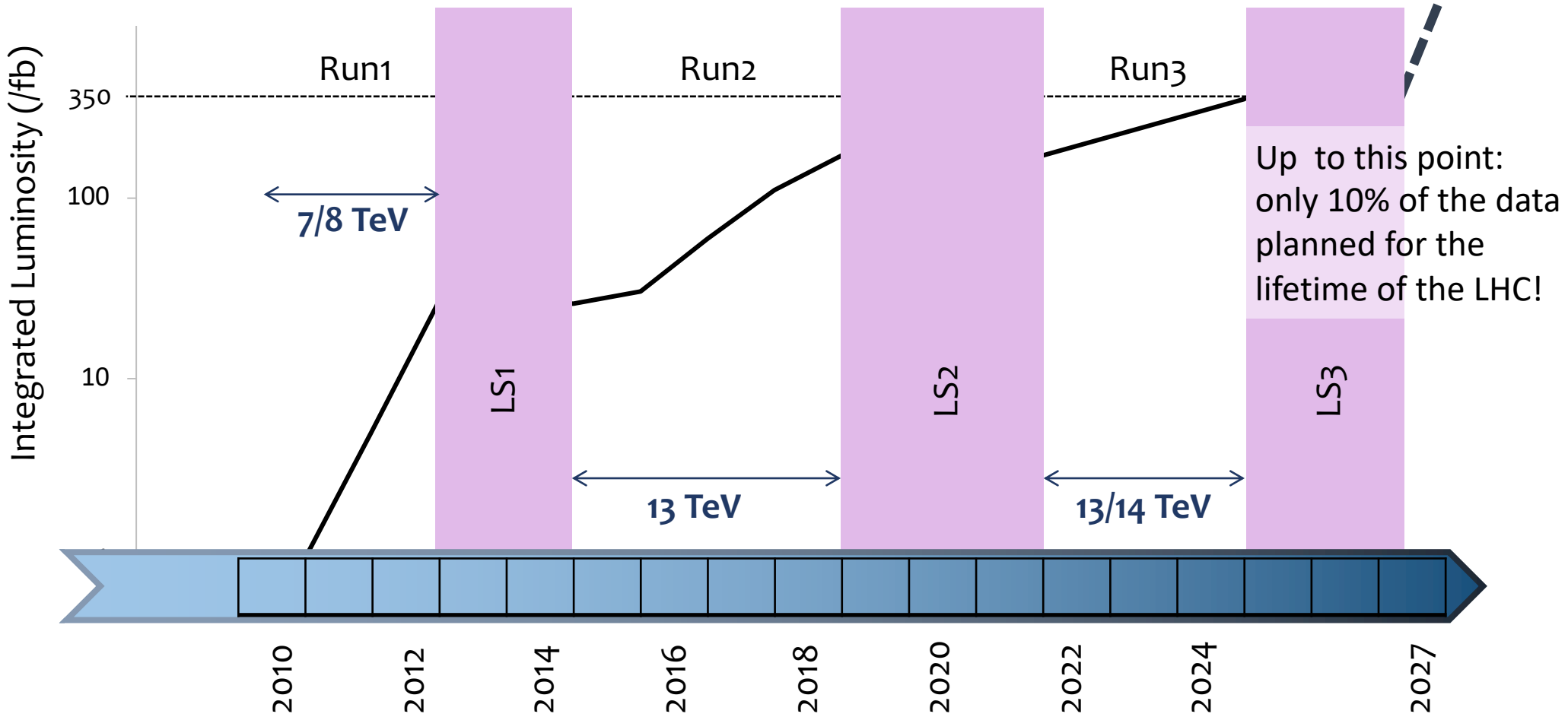


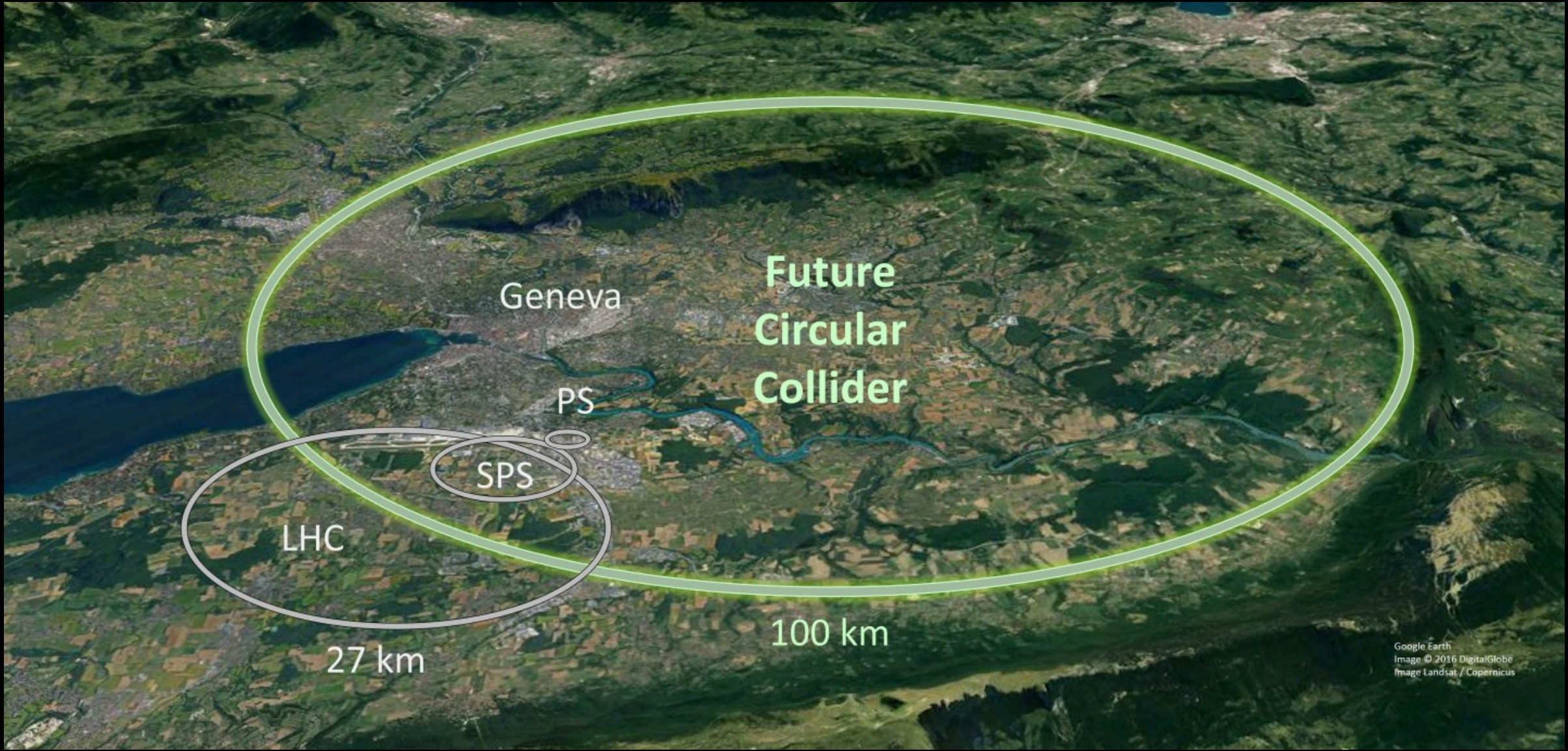
Look at higher energies





Run1, Run2 and beyond





Geneva

Future
Circular
Collider

PS

SPS

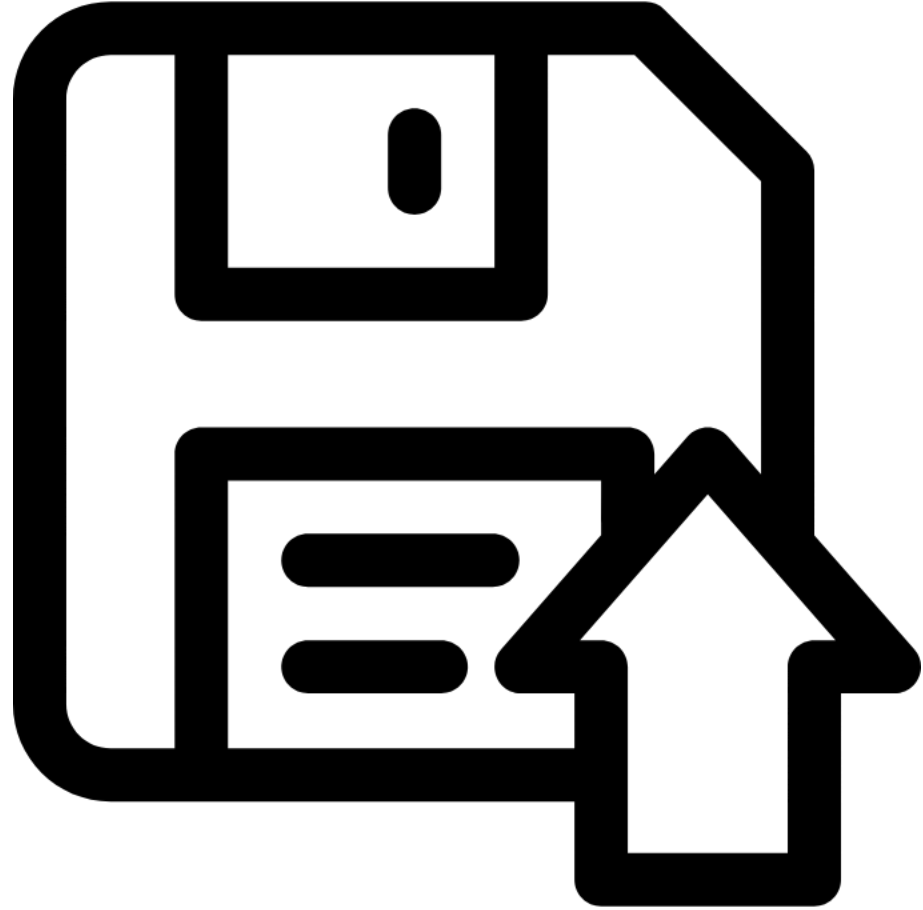
LHC

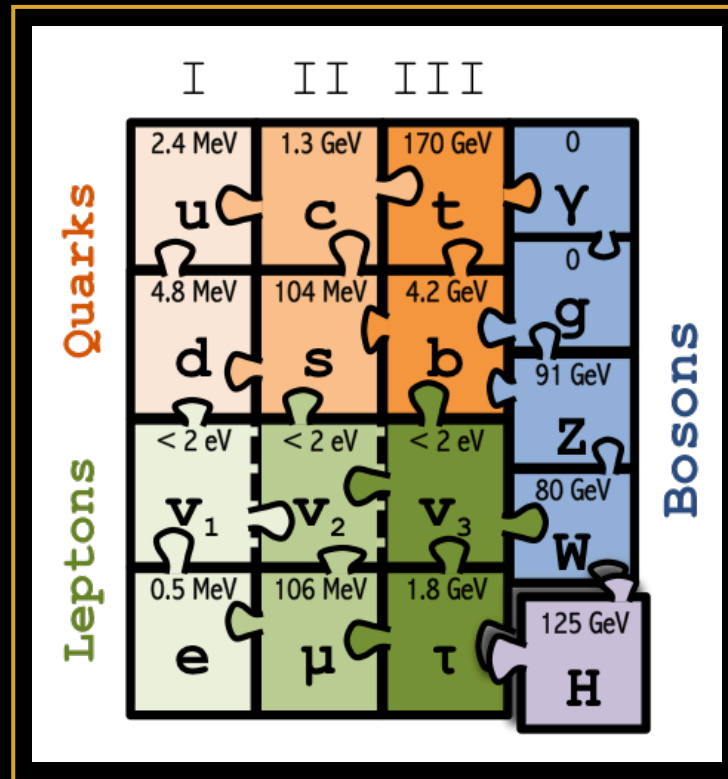
27 km

100 km

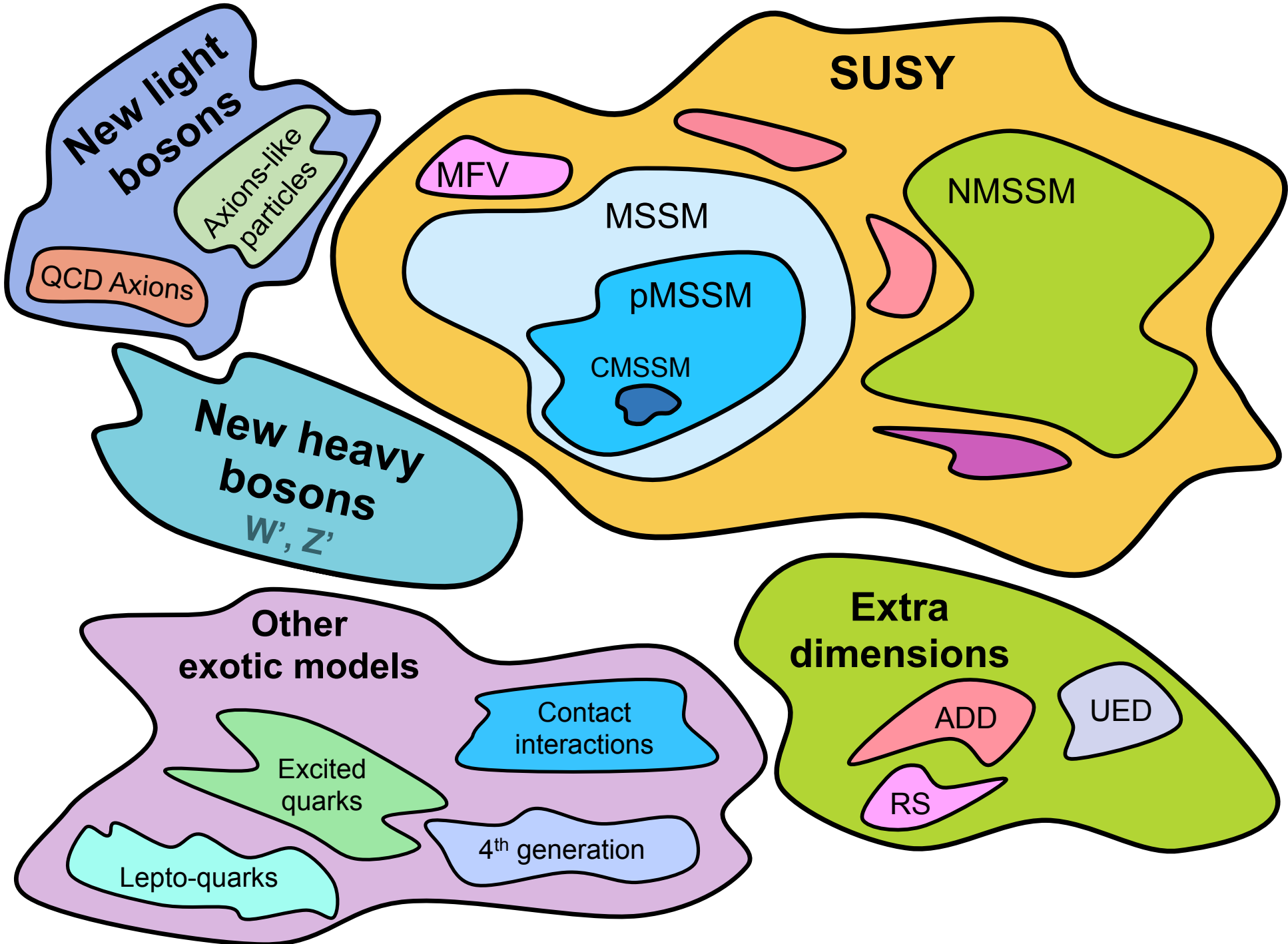


@DPNC_Unige @ATLASexperiment @FASERexperiment @FCC_study



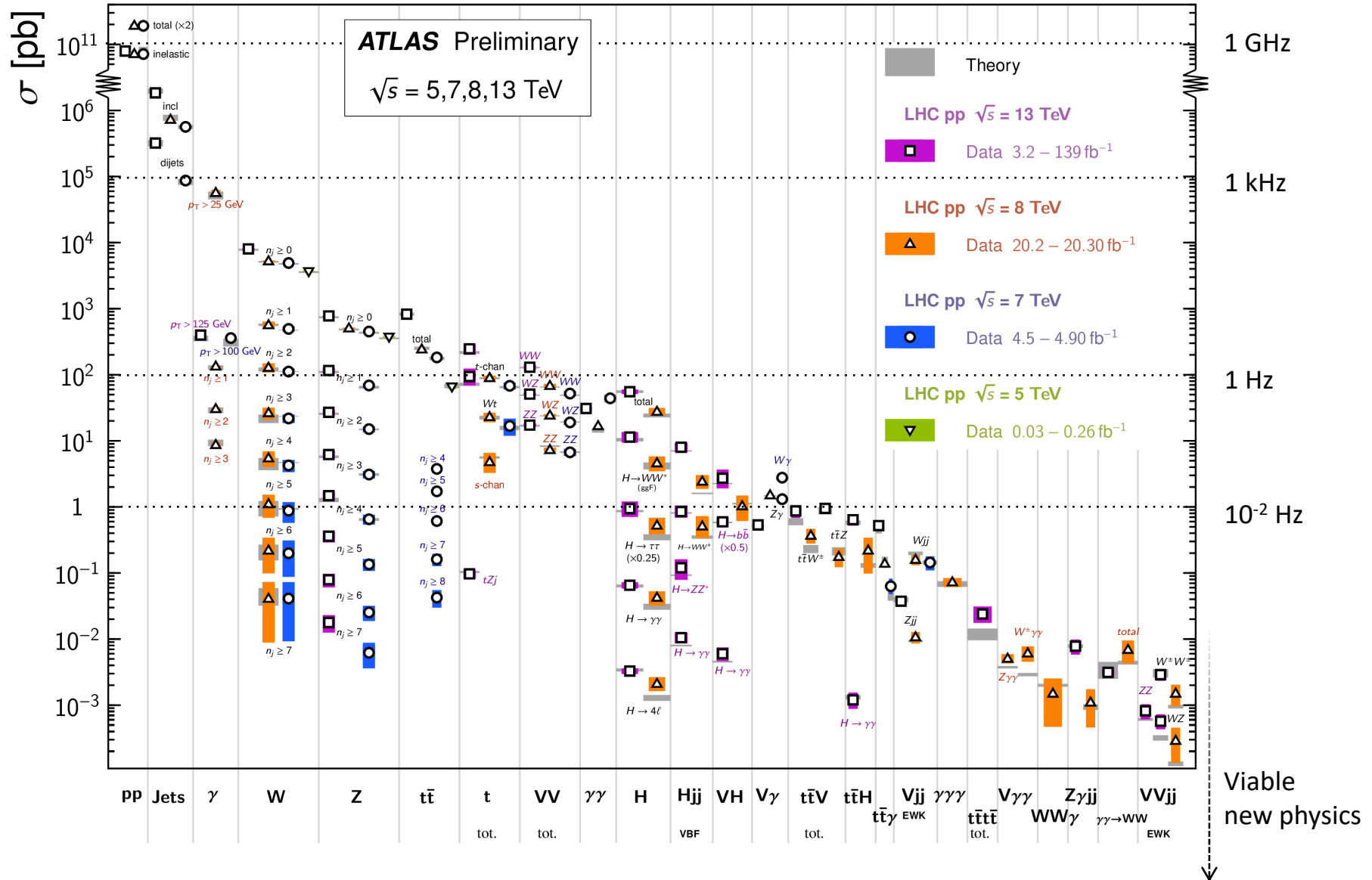


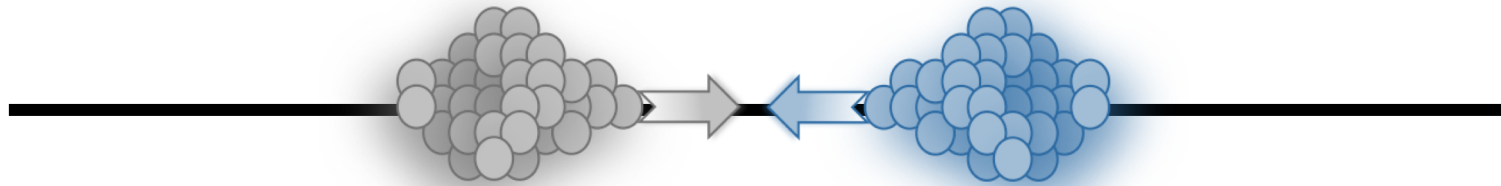
- Why are there three families of quarks and leptons?
- What is the origin of the different quark and lepton masses?
- Is there a further substructure of fundamental particles?
- Are there more fundamental forces at the microscopic level?
- What is the nature of the Higgs boson?



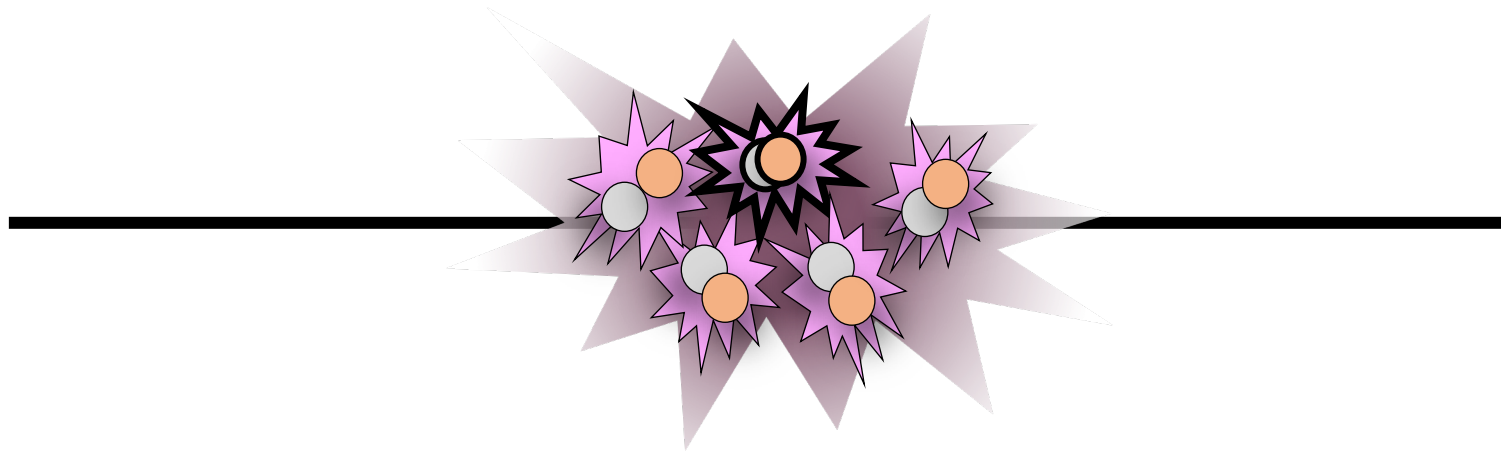
Standard Model Production Cross Section Measurements

Status: March 2021



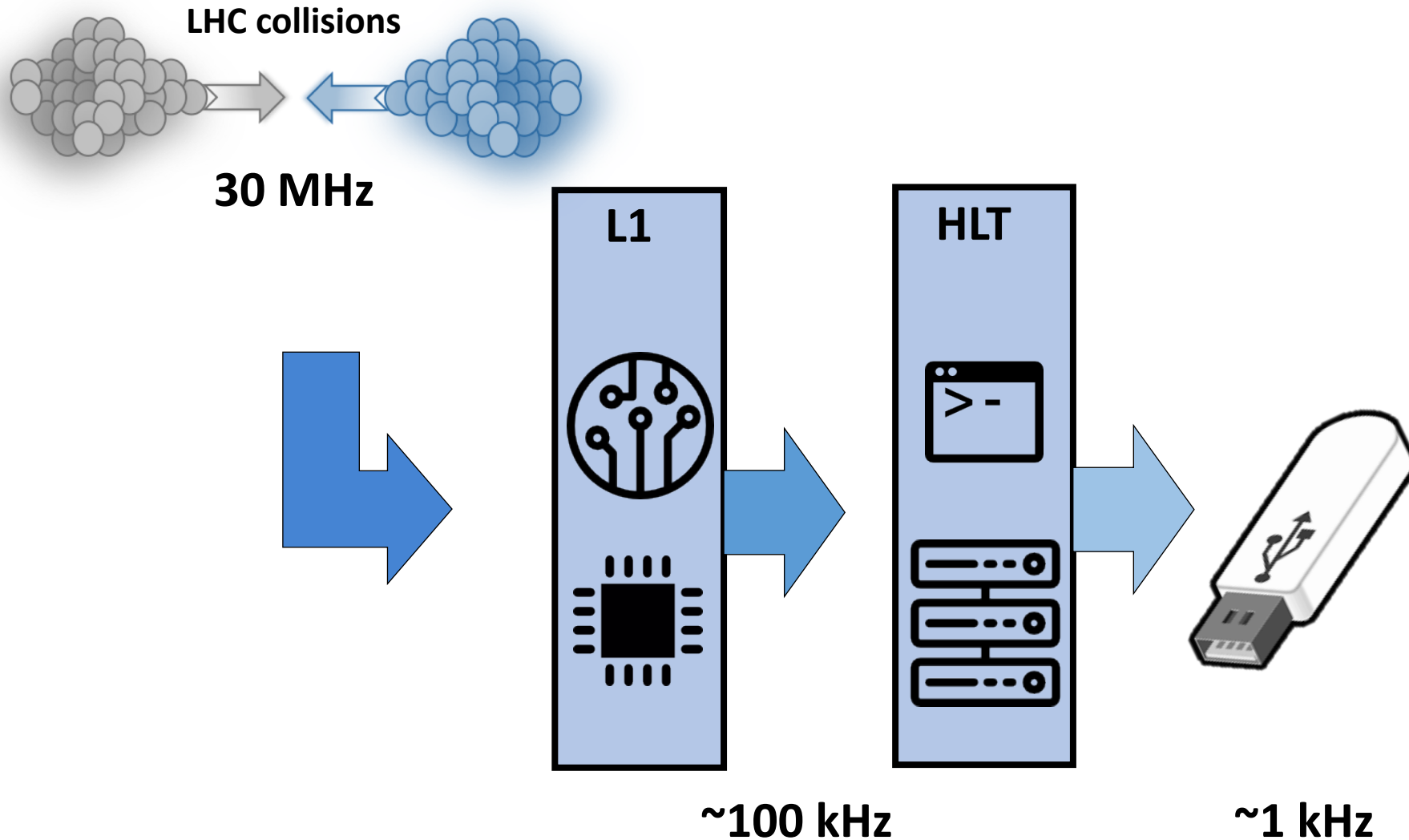


Proton bunches
>10¹¹ protons/bunch
(colliding at ~30MHz in Run2)

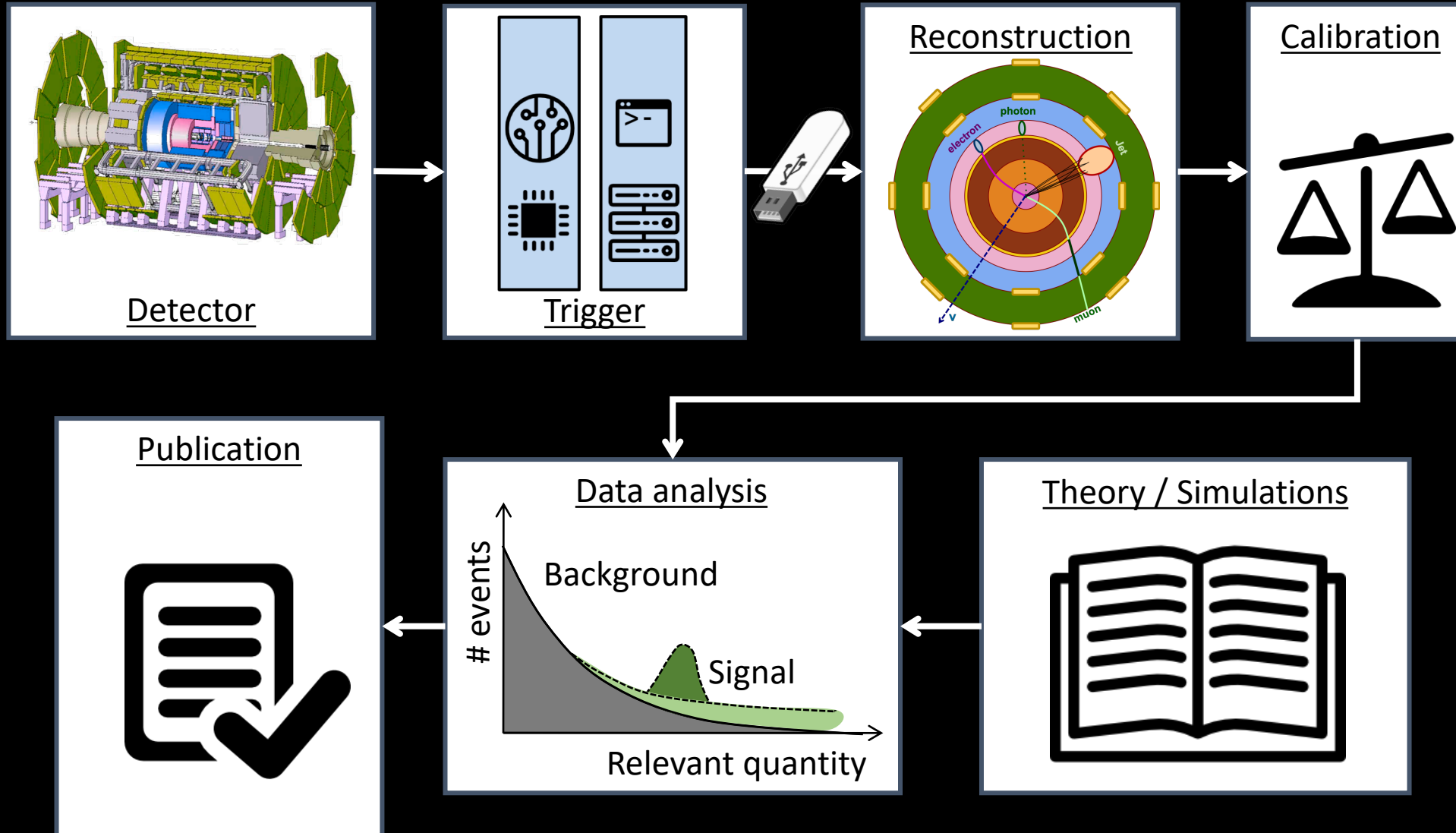


Up to 60 p-p collisions / bunch crossing

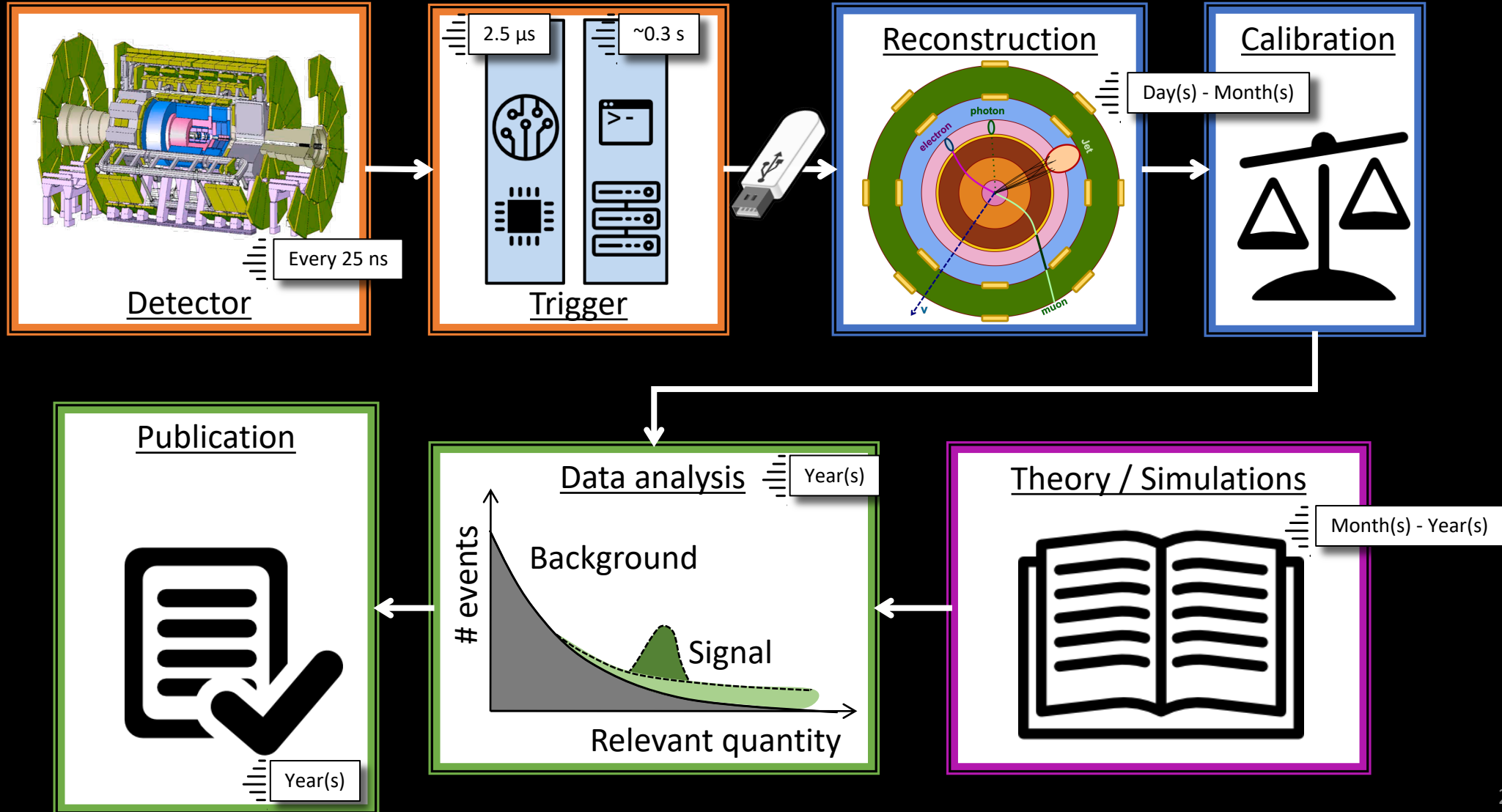
Triggering on physics



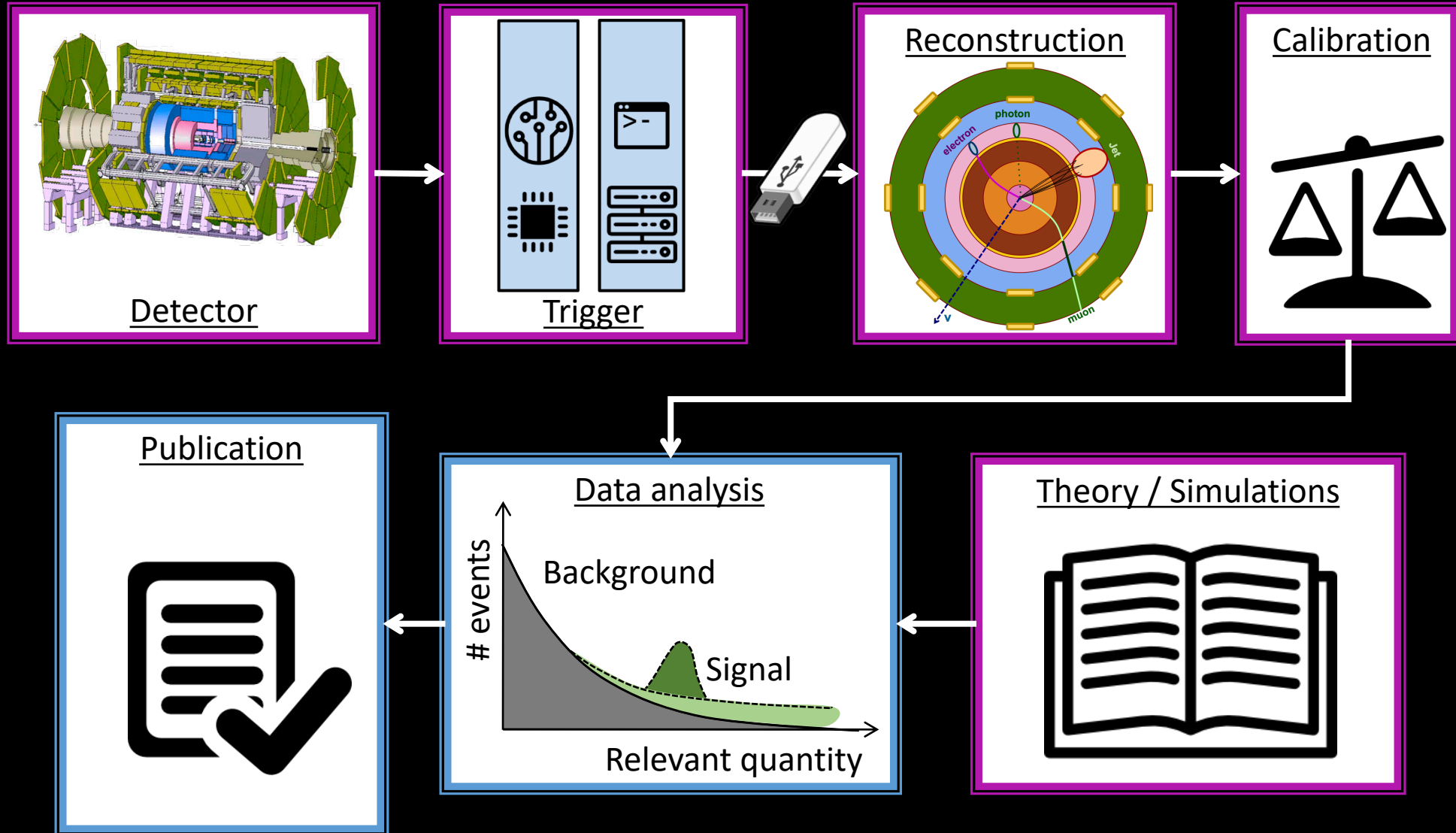
An event's lifetime



An event's lifetime

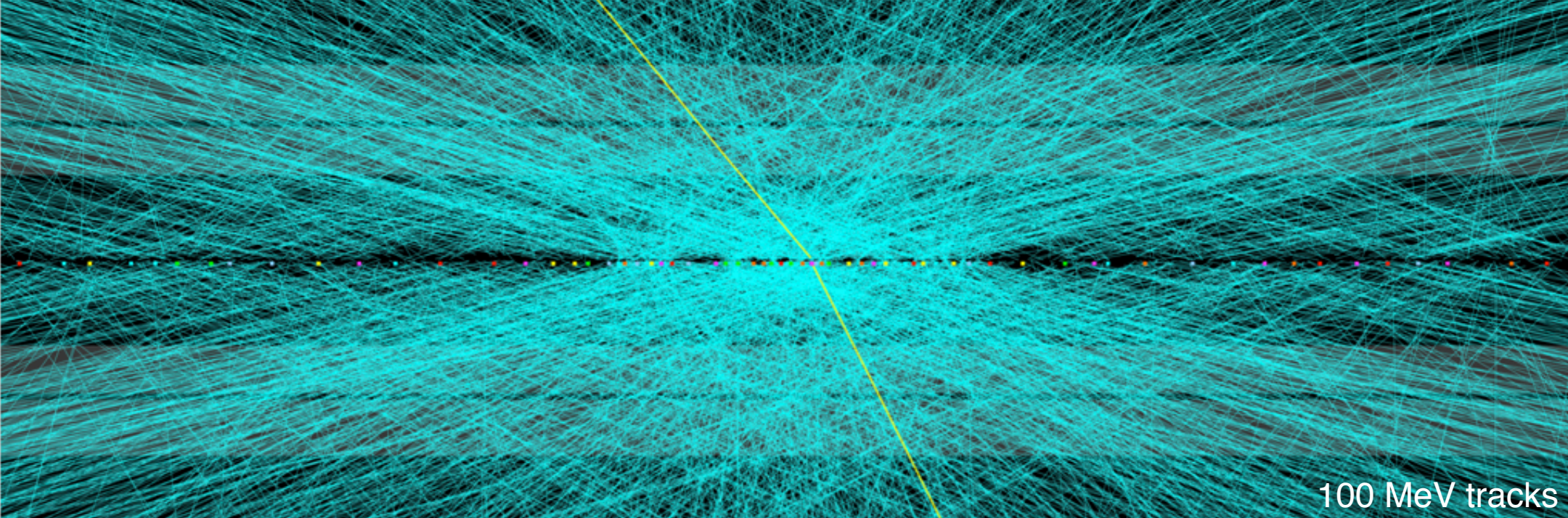


An event's lifetime

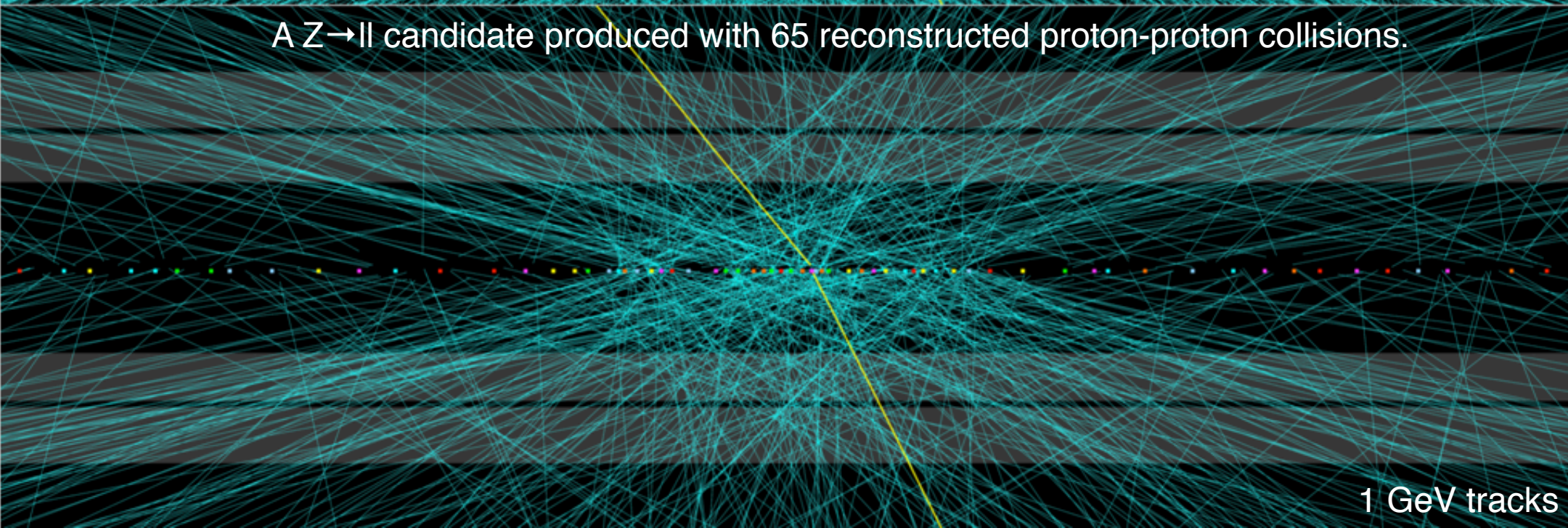


Analysis team

ATLAS Collaboration



A $Z \rightarrow \ell\ell$ candidate produced with 65 reconstructed proton-proton collisions.



Why? >>> Guarantee openness and preservation of experimental data

New open data policy in support of open science from CERN & the LHC experiments

Peer-reviewed publications

- Open Access
- Followed by detailed data related to the results, available at hepdata.net



Purpose: Communicate results and maximize their scientific value

Reconstructed & calibrated data

- Followed by related metadata
- Accompanied by appropriate simulated data samples



Purpose: Algorithmic, performance and physics studies

Data for outreach and education

- Selected and formatted (“light”) datasets
- Examples available in Jupyter notebooks
- Used in university classes, in growing numbers



Purpose: Maximize educational impact

More info: <https://atlas.cern/resources/opendata>



Searching for the Higgs boson in the $H \rightarrow \gamma\gamma$ channel

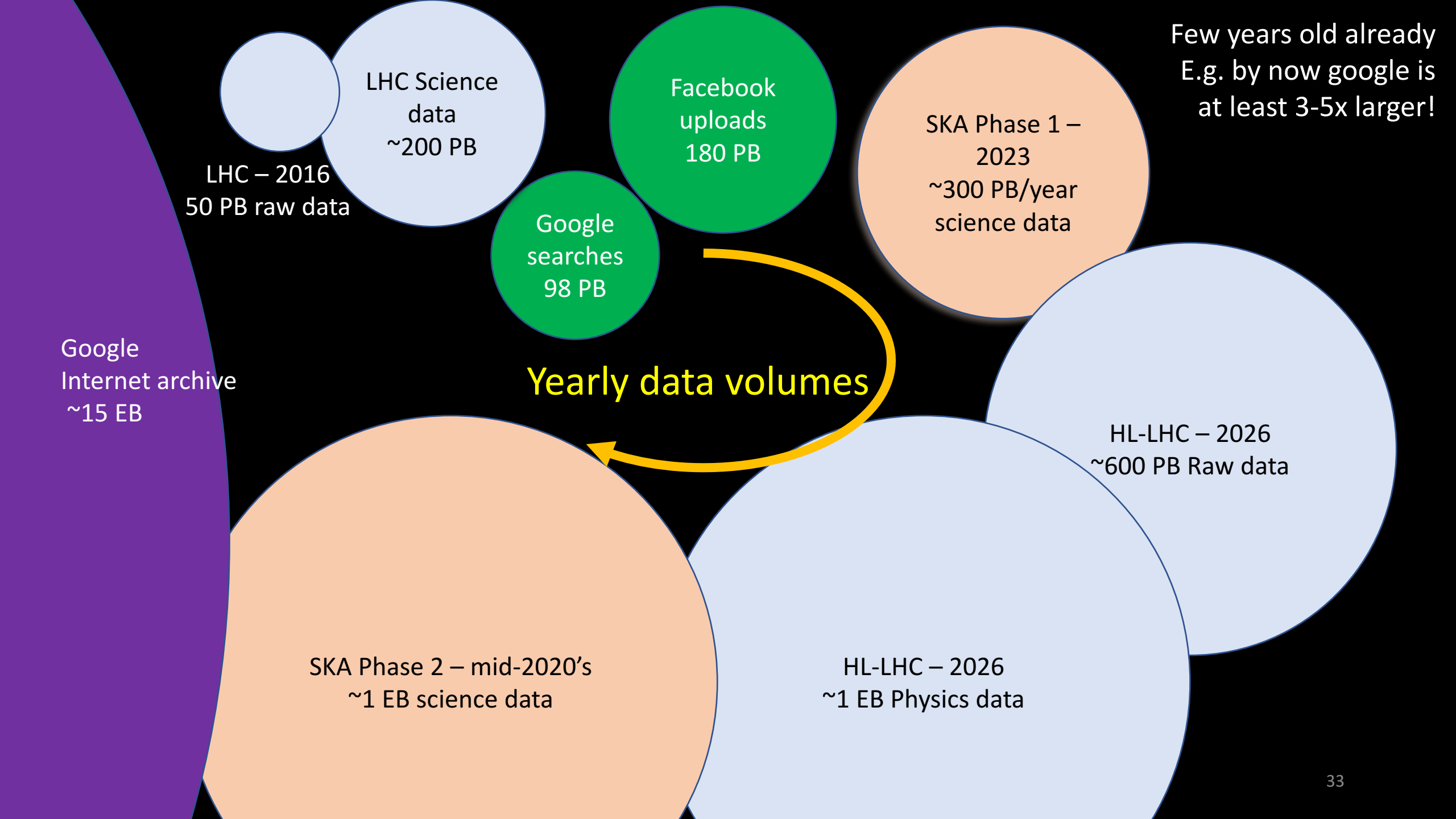
Python notebook example

Introduction Let's take a current ATLAS Open Data sample and create a histogram:

```
In [1]: import ROOT
        from ROOT import TMath
        import time
```

Welcome to JupyROOT 6.07/03

```
In [2]: start = time.time()
```



- “The acronym recalls another marvelous instrument that harnessed highly collimated particles and was used to explore strange new worlds.”

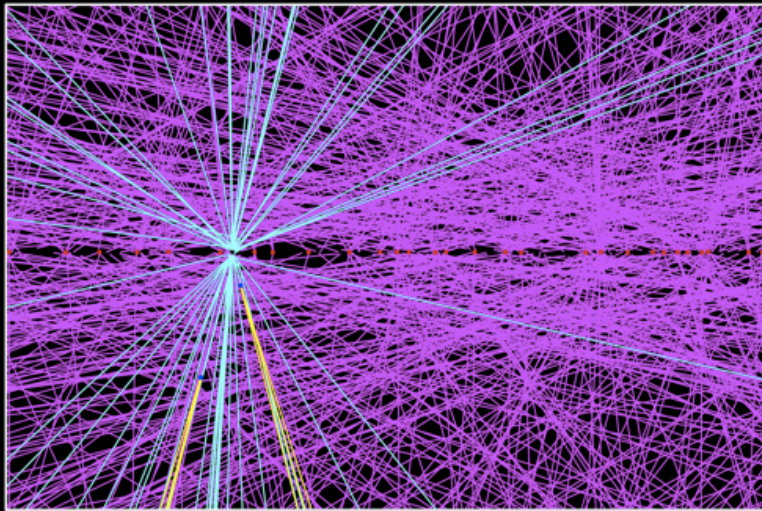
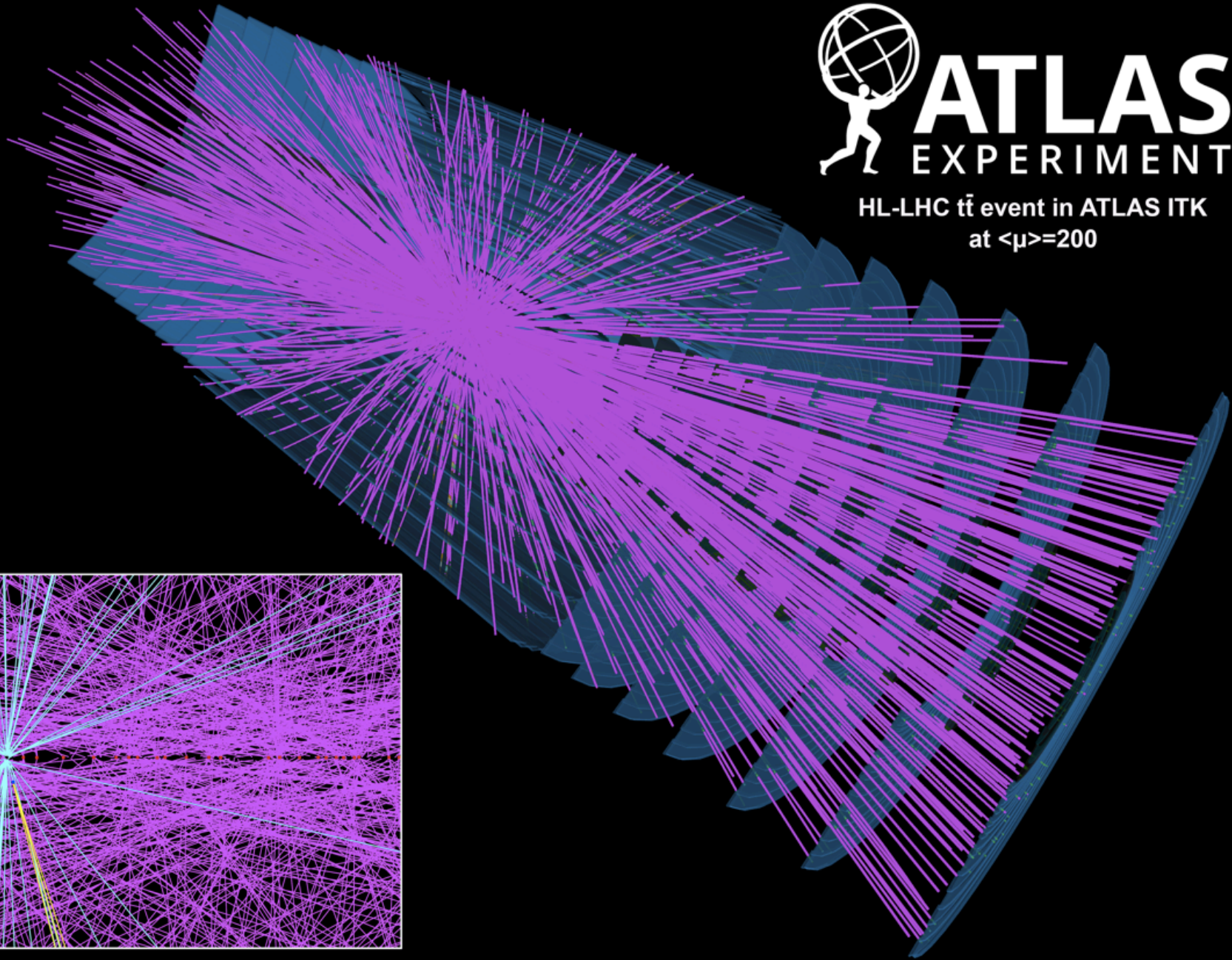
Feng, Galon, Kling, Trojanowski (2017)





ATLAS EXPERIMENT

HL-LHC $t\bar{t}$ event in ATLAS ITK
at $\langle\mu\rangle=200$



Timeline of collider projects

