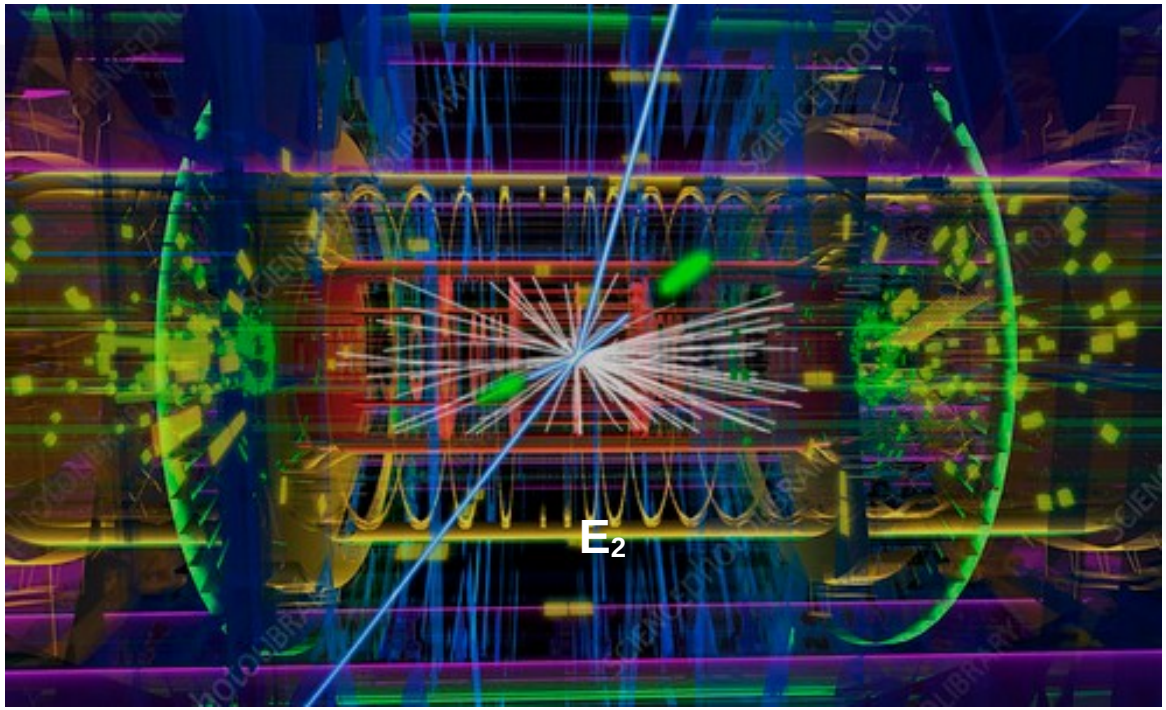
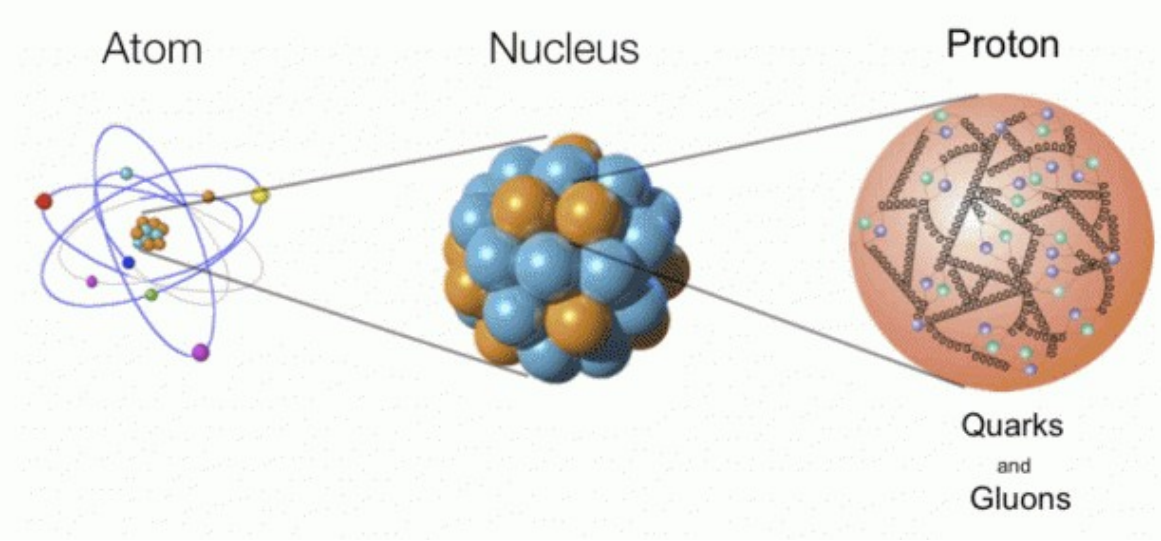
Поиск новых частиц на Большом адронном коллайдере (БАК - Large Hadron Collider)

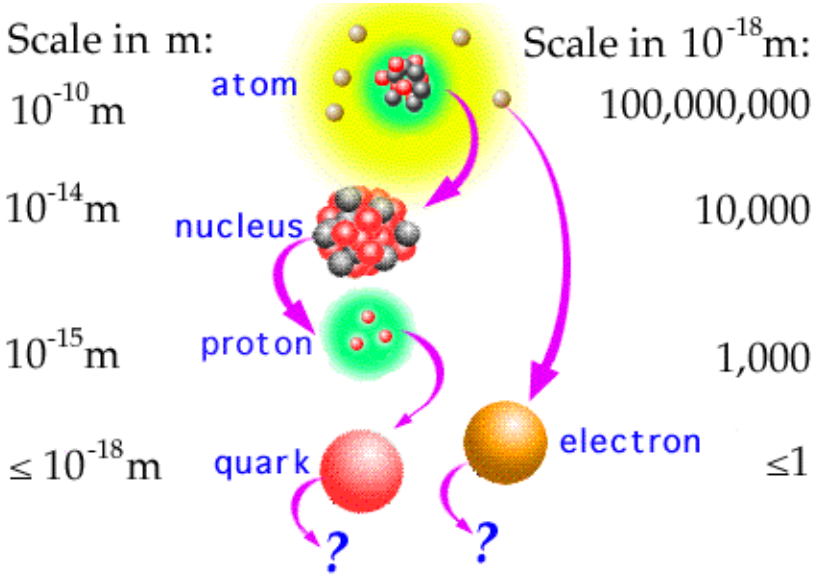
S.Chekanov (ANL)

RASA2023, XIV International Conference
Northwestern University, Illinois, USA



БАК - Large Hadron Collider





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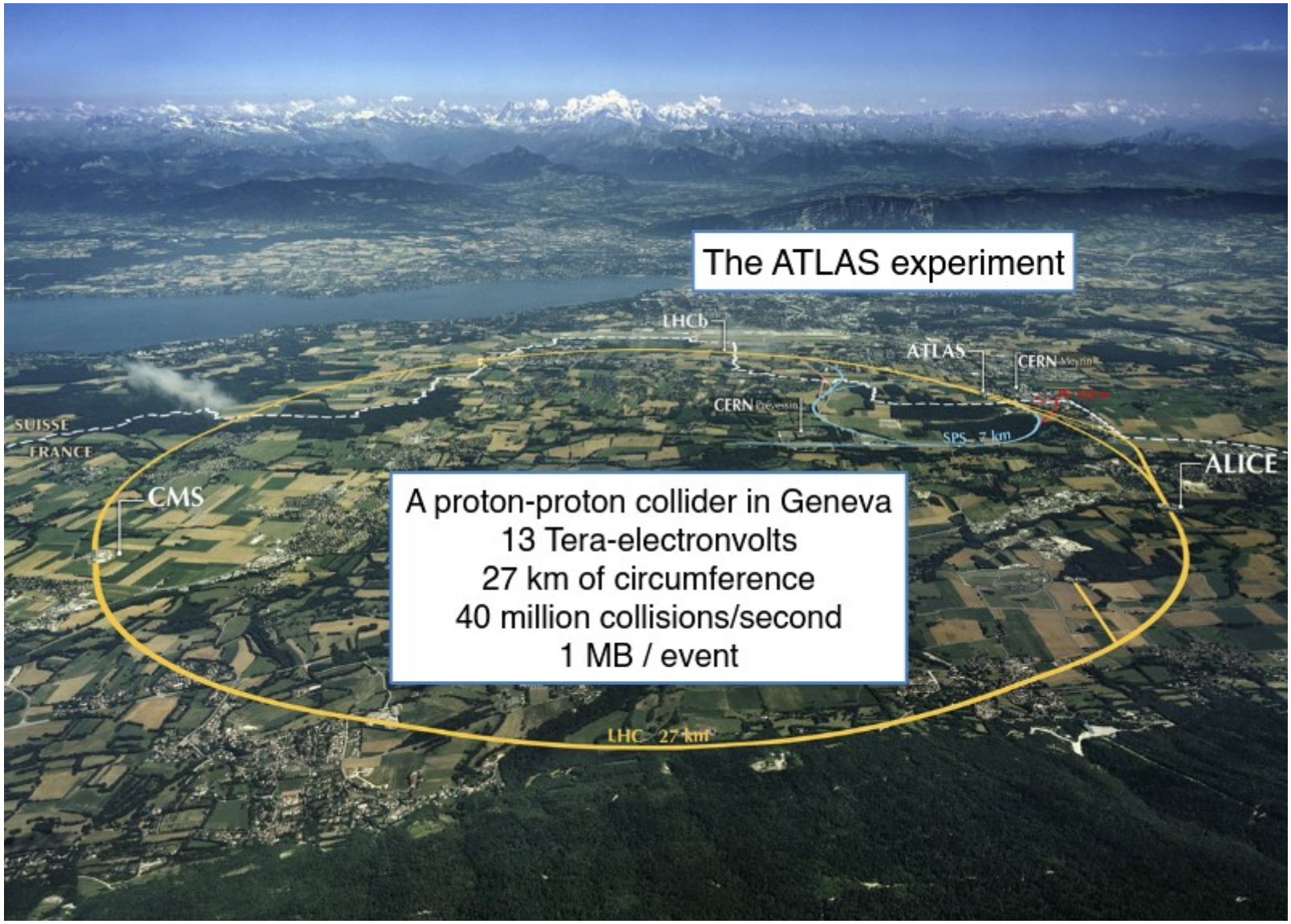

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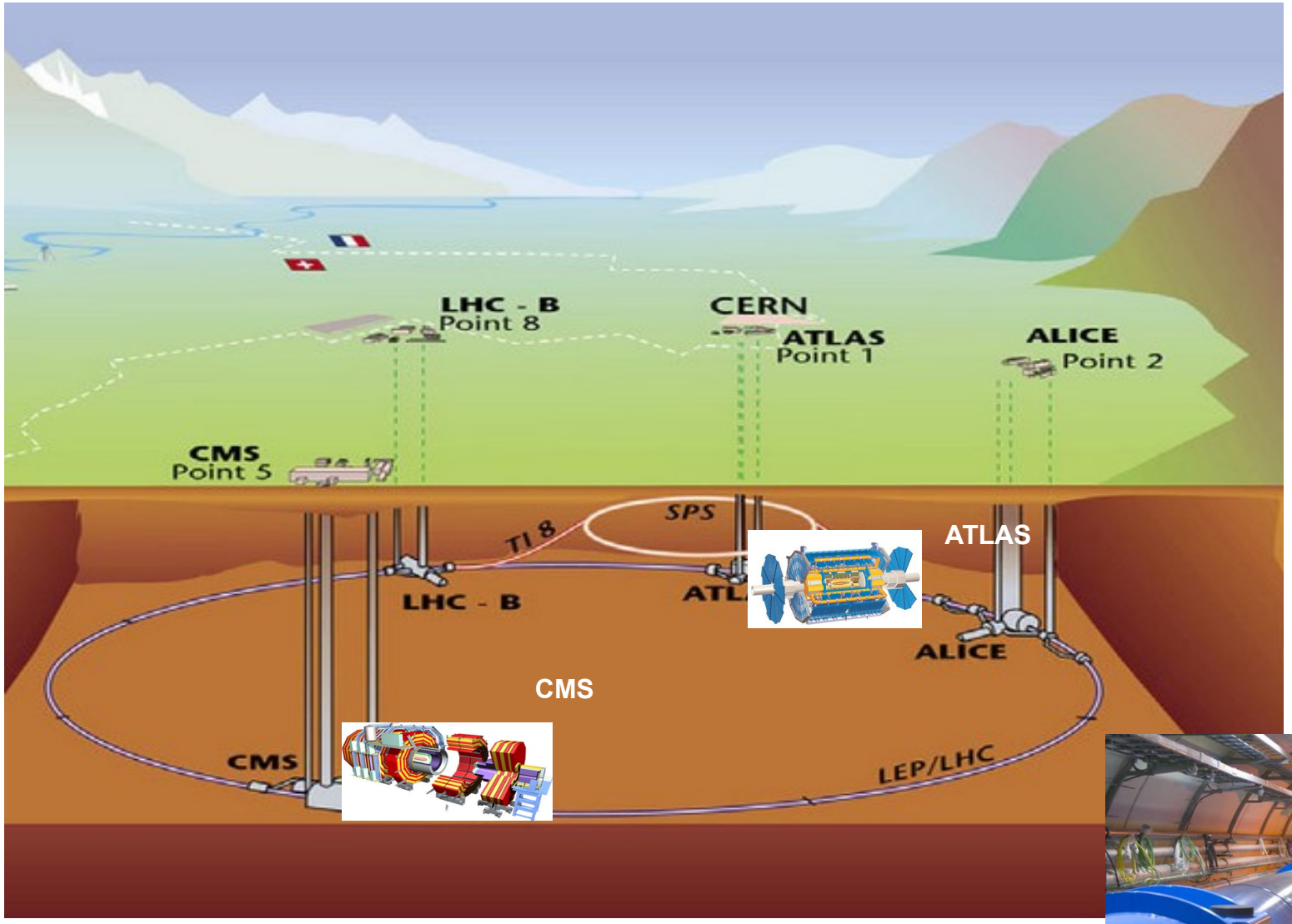
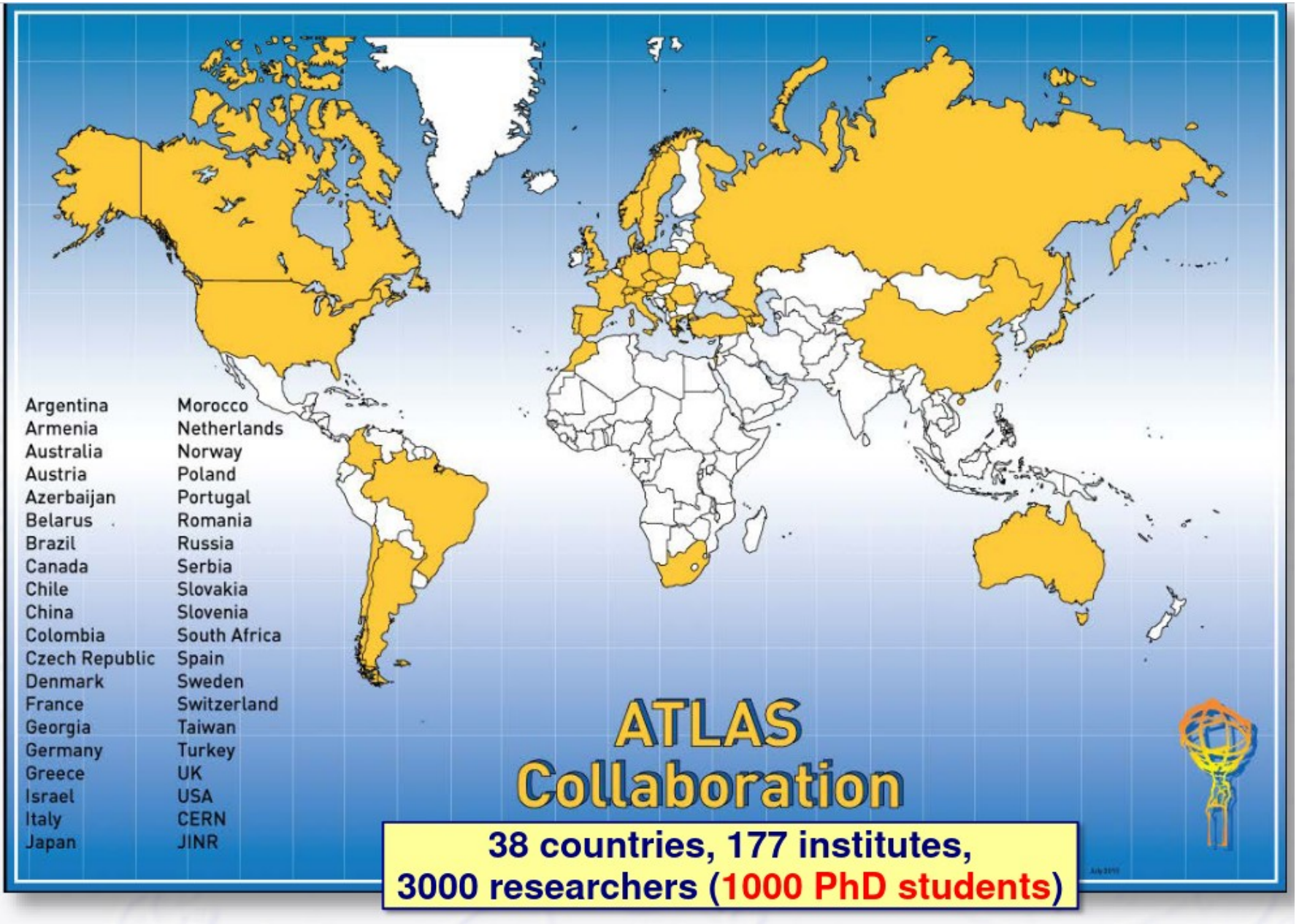
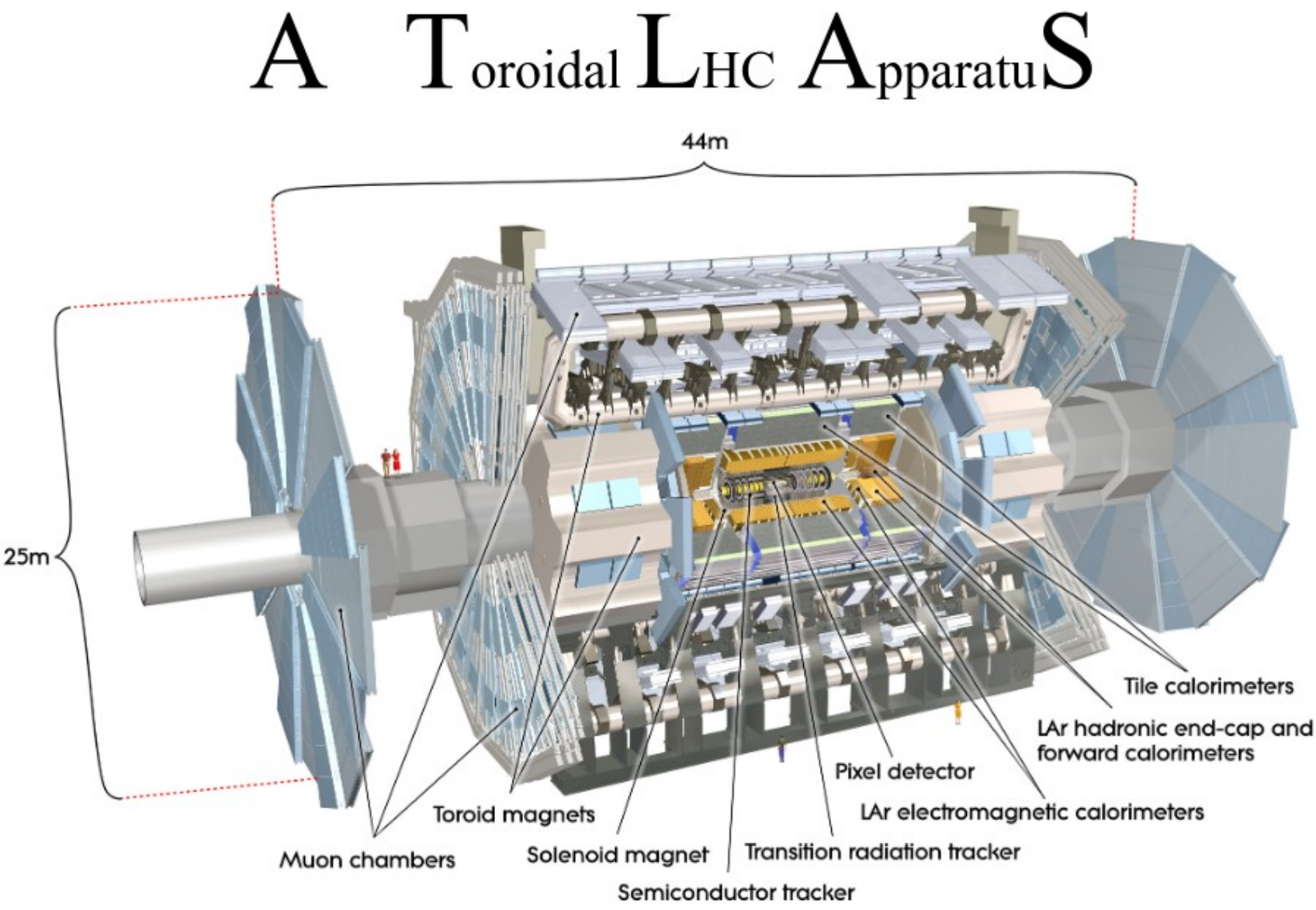


ATLAS эксперимент

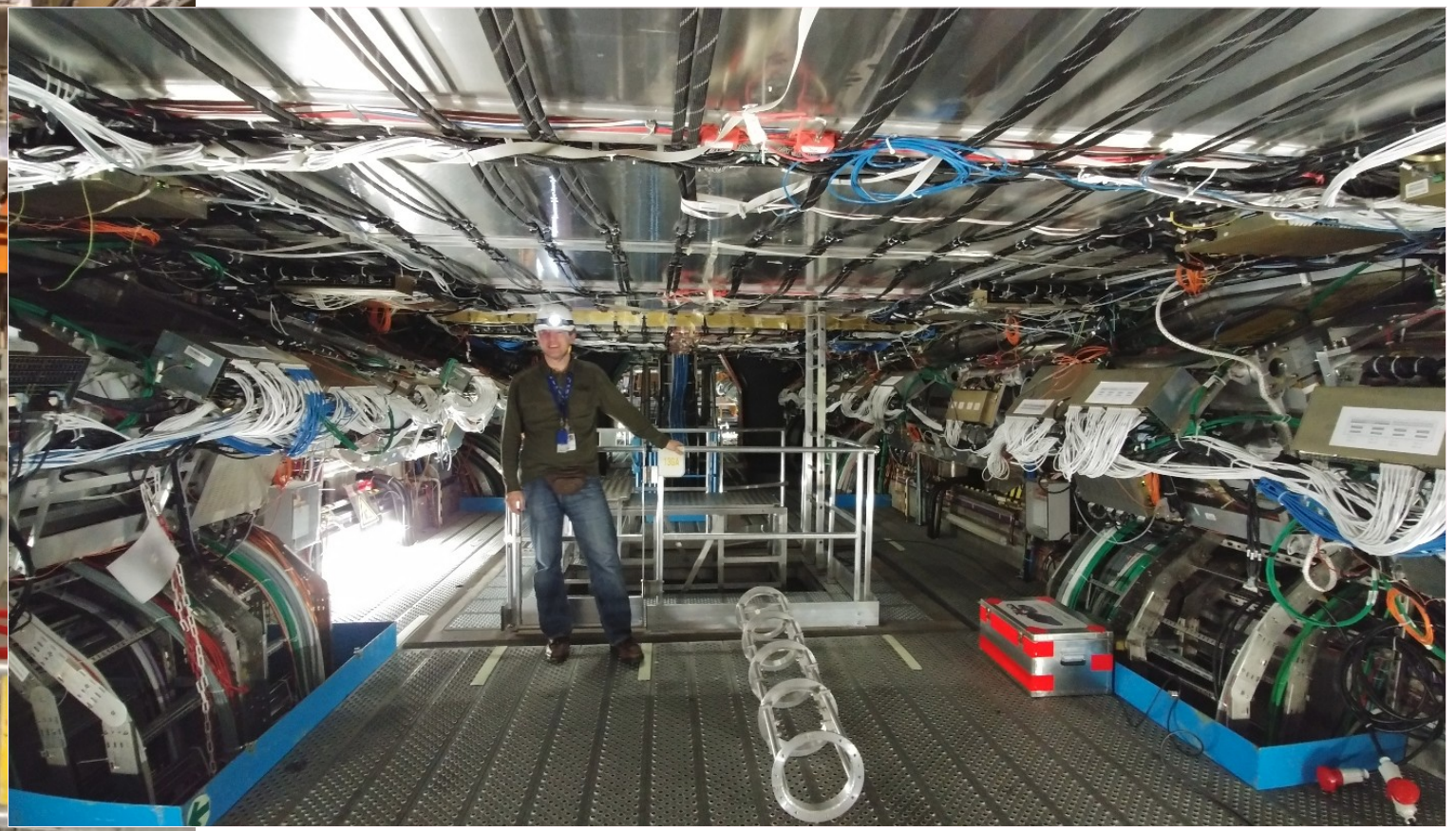


ATLAS детектор



ATLAS детектор

~ 7000 tons



Хиггс бозон

- Focus Energy into tiny spot → produce new matter / energy E = mc^2

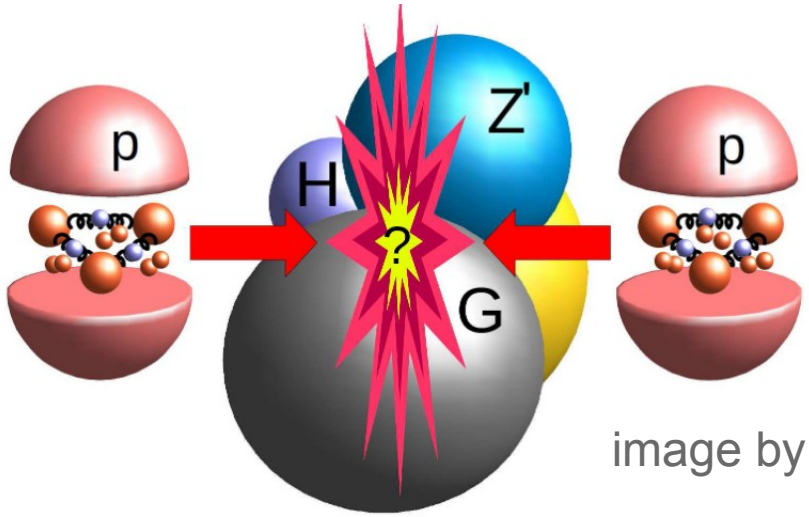
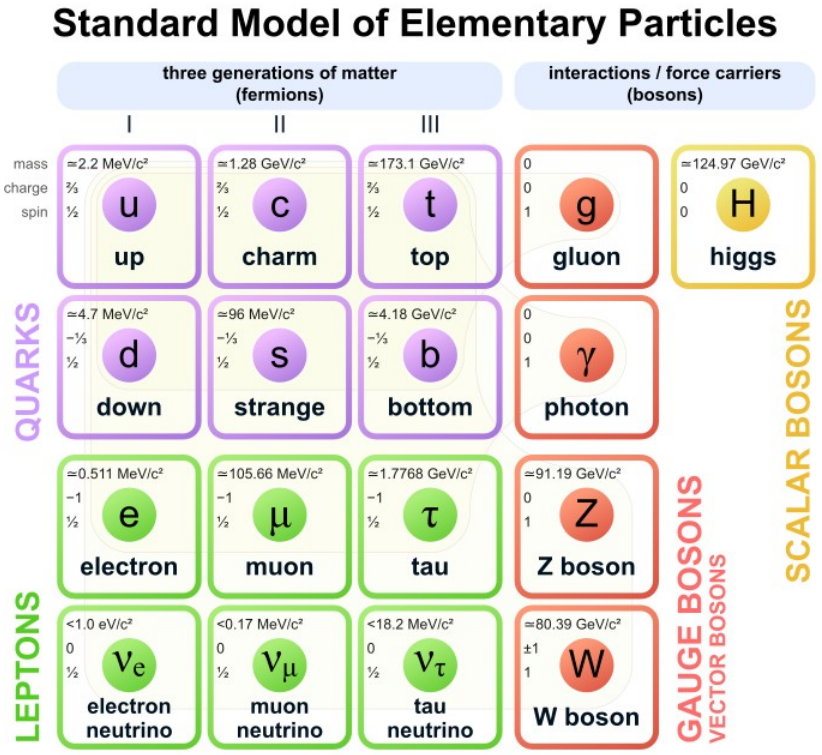


image by A.Gritsan

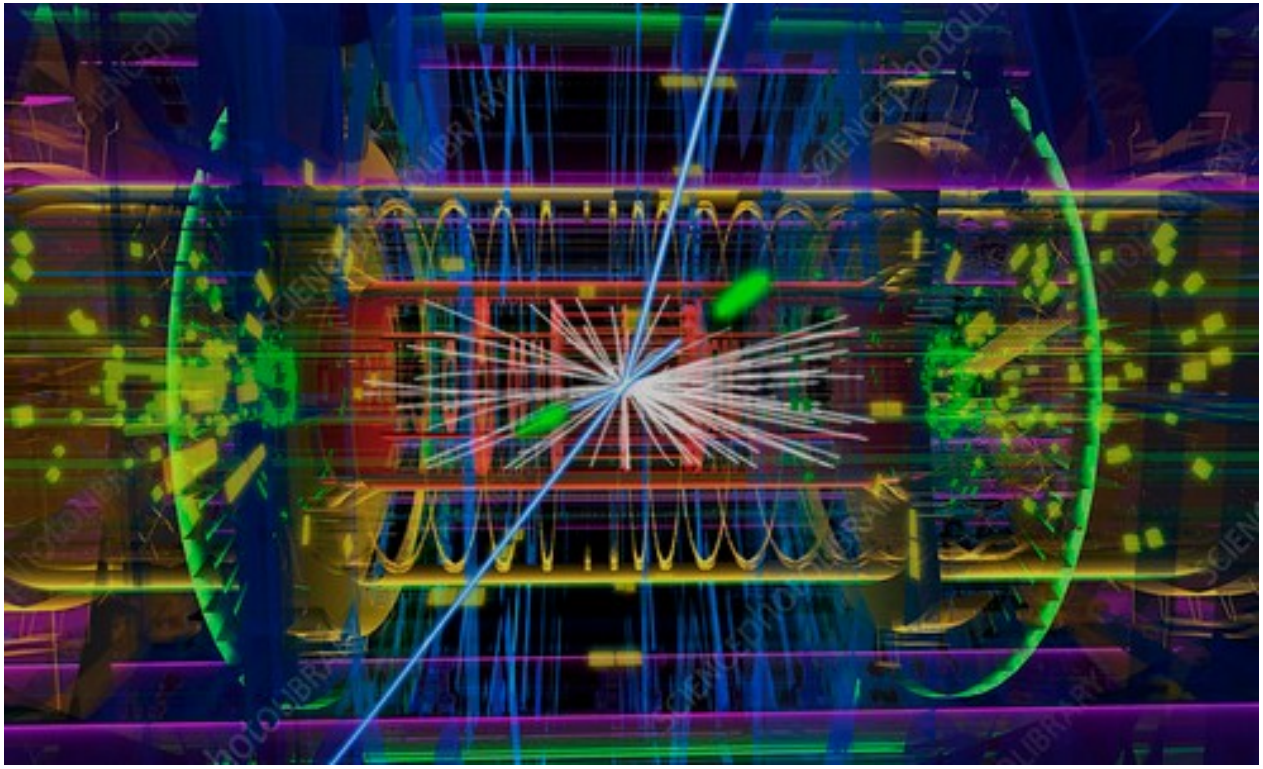


- 2012: Discovery of Higgs bosons at the LHC at the mass 125 GeV
- All elemental articles get mass from Higgs Field
- How was it found? Higgs is boson → should decay to photons!

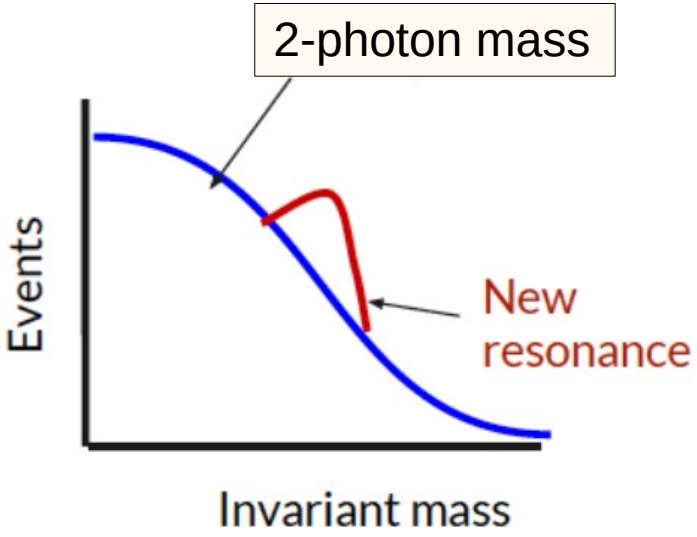
Как найти Хиггс бозон (или любую новую частицу)

photon 1 (E=60 GeV)

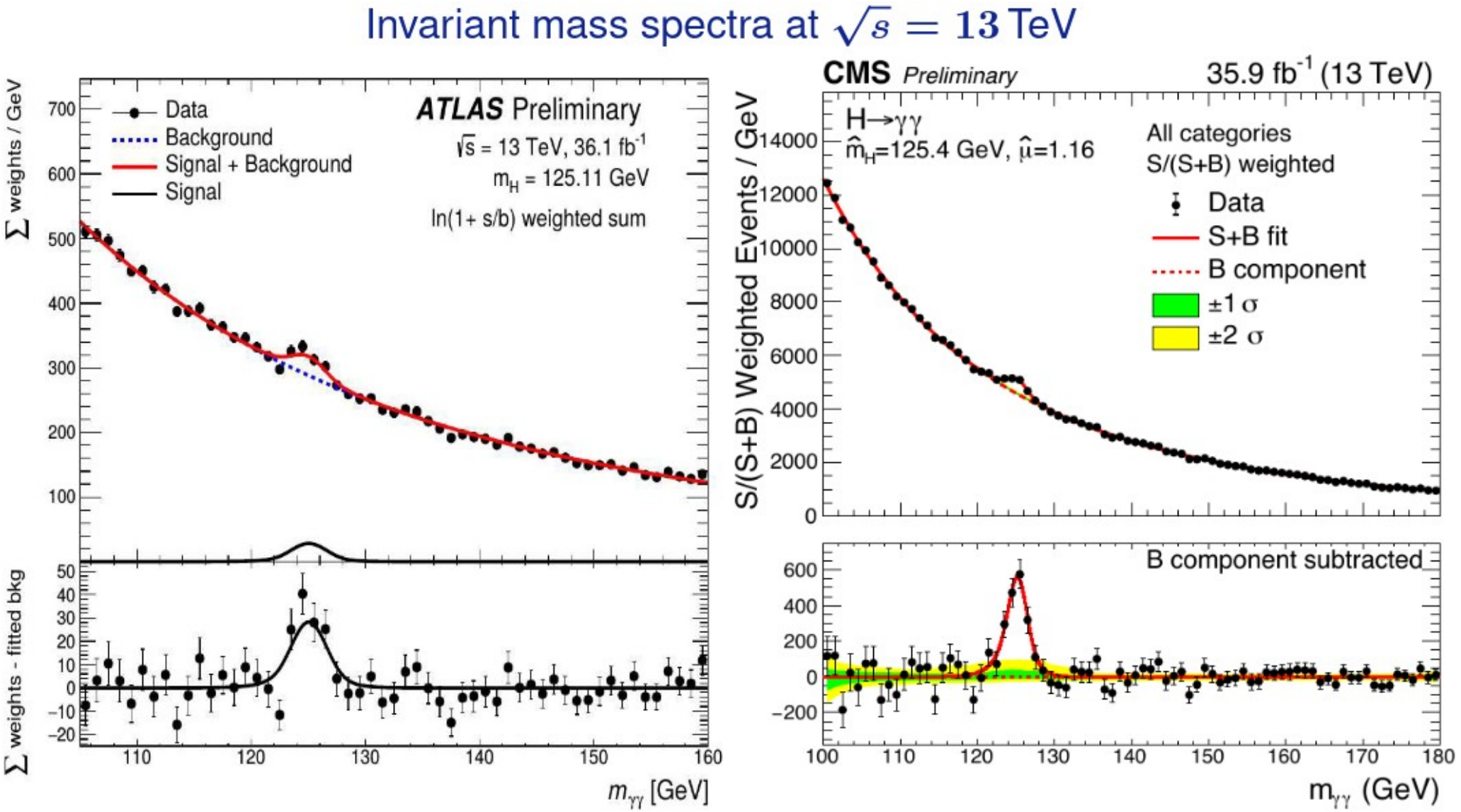
$$M^2 = (E_1 + E_2)^2 - \|\mathbf{p}_1 + \mathbf{p}_2\|^2$$



photon 2 (E=65 GeV)

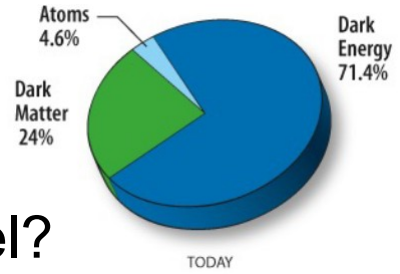


Как найти Хиггс бозон (или любую новую частицу)

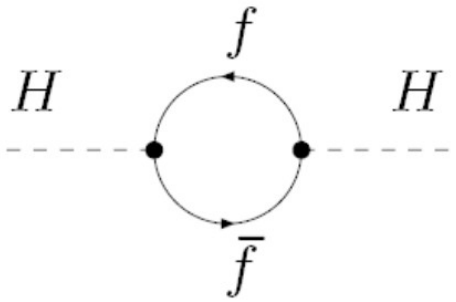


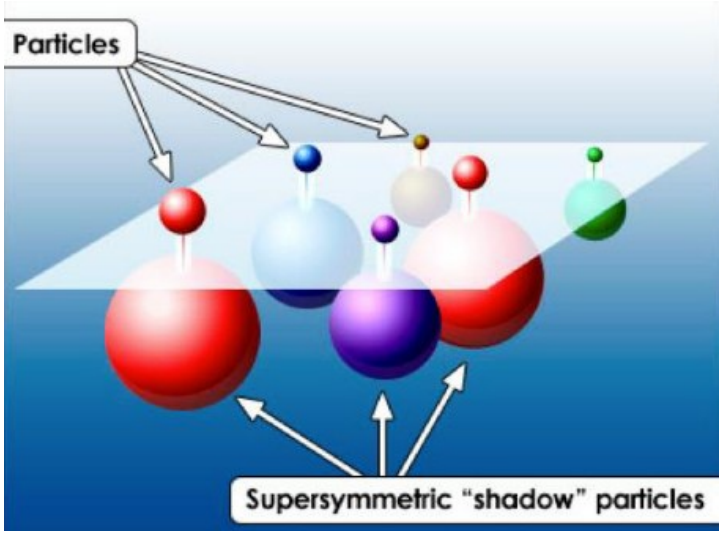
Много открытых вопросов

- What is the origin of the Higgs?
- What is the origin of dark matter and dark energy?
- Matter and almost no antimatter
- What is the origin of ~20 free parameters of Standard Model?
- What is origin of fine tuning in the Standard Model?



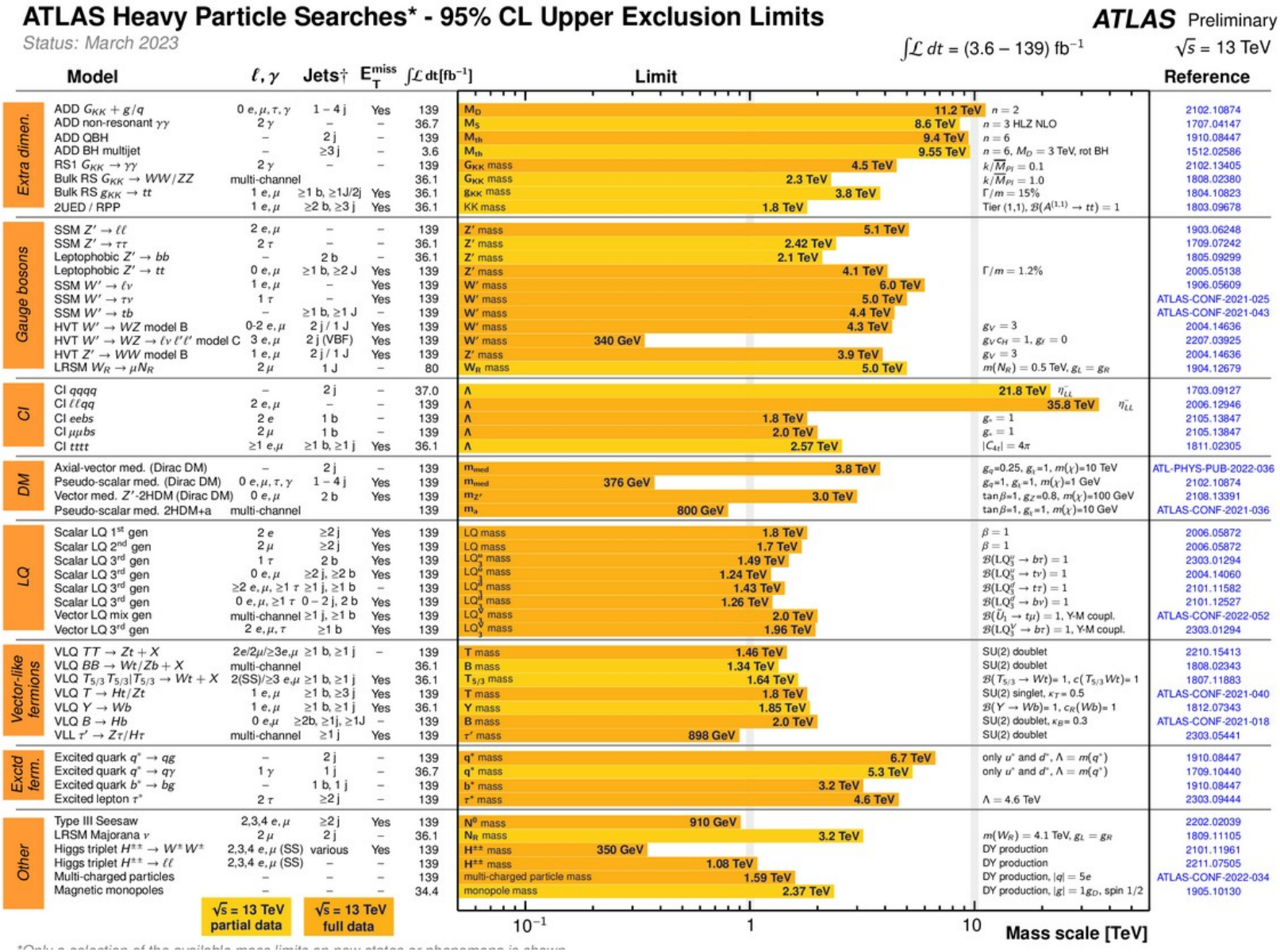
Example:
Higgs mass is a measured parameter, but it mass should be very large if we calculate it from a theory large contributions from quadratic diverges due to radiative corrections.





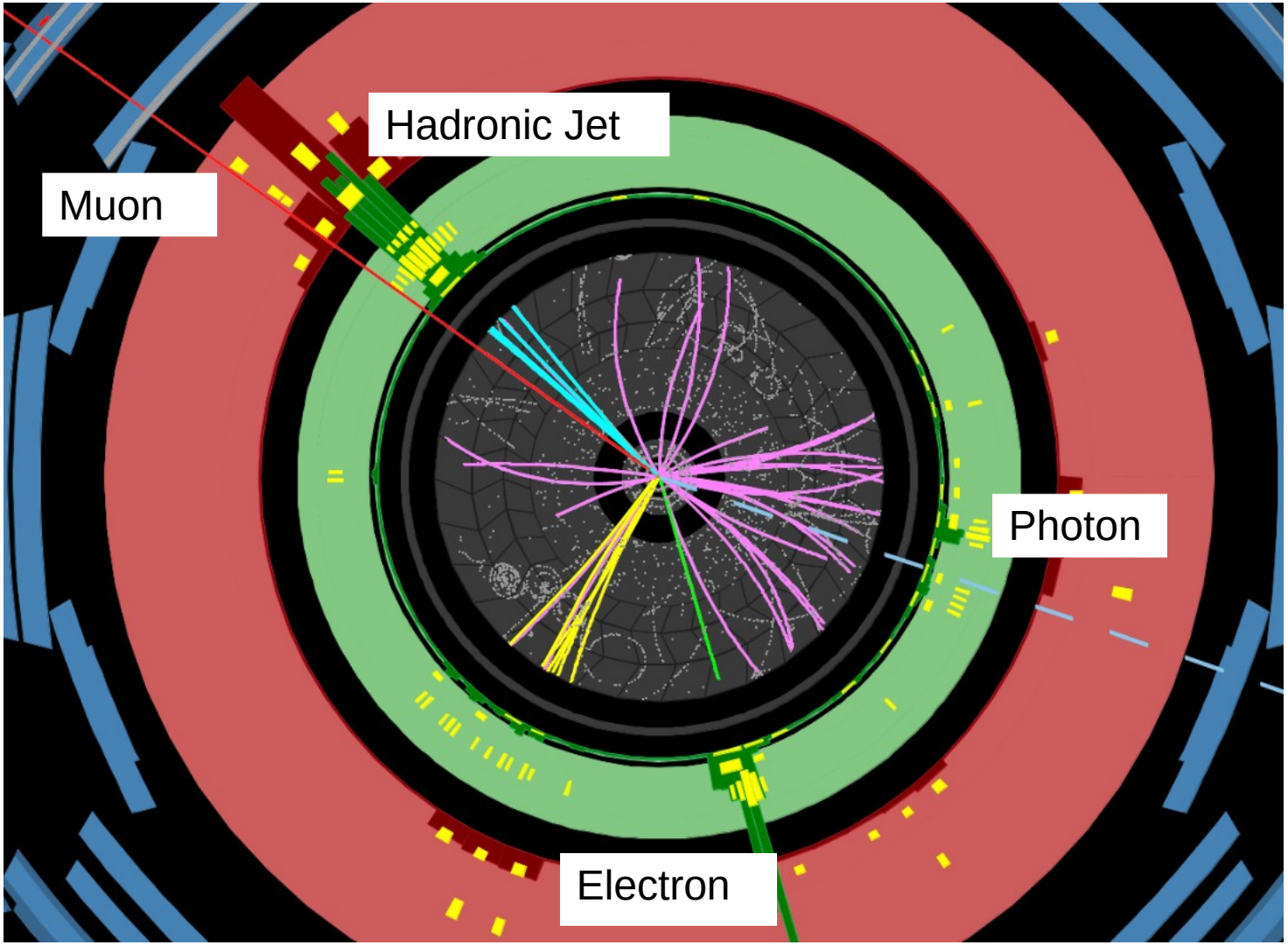
In order for the Higgs boson mass to be finite, a fine tuning (cancellation) of various loops is required ("hierarchy problem") **New particles** can cancel such divergencies and will lead to the finite 125 GeV mass

LHC searches for new particles (ATLAS only)



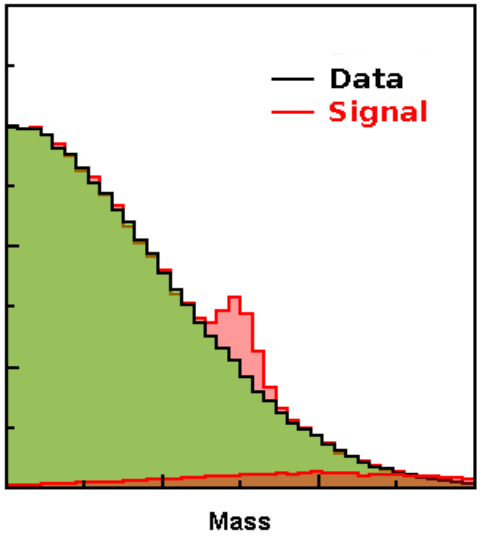
~90% of searches are done by comparing data with Monte Carlo simulations predicting new particles

Как найти новую частицу независимым от модели способом



Combine 2 particles (or jets) together

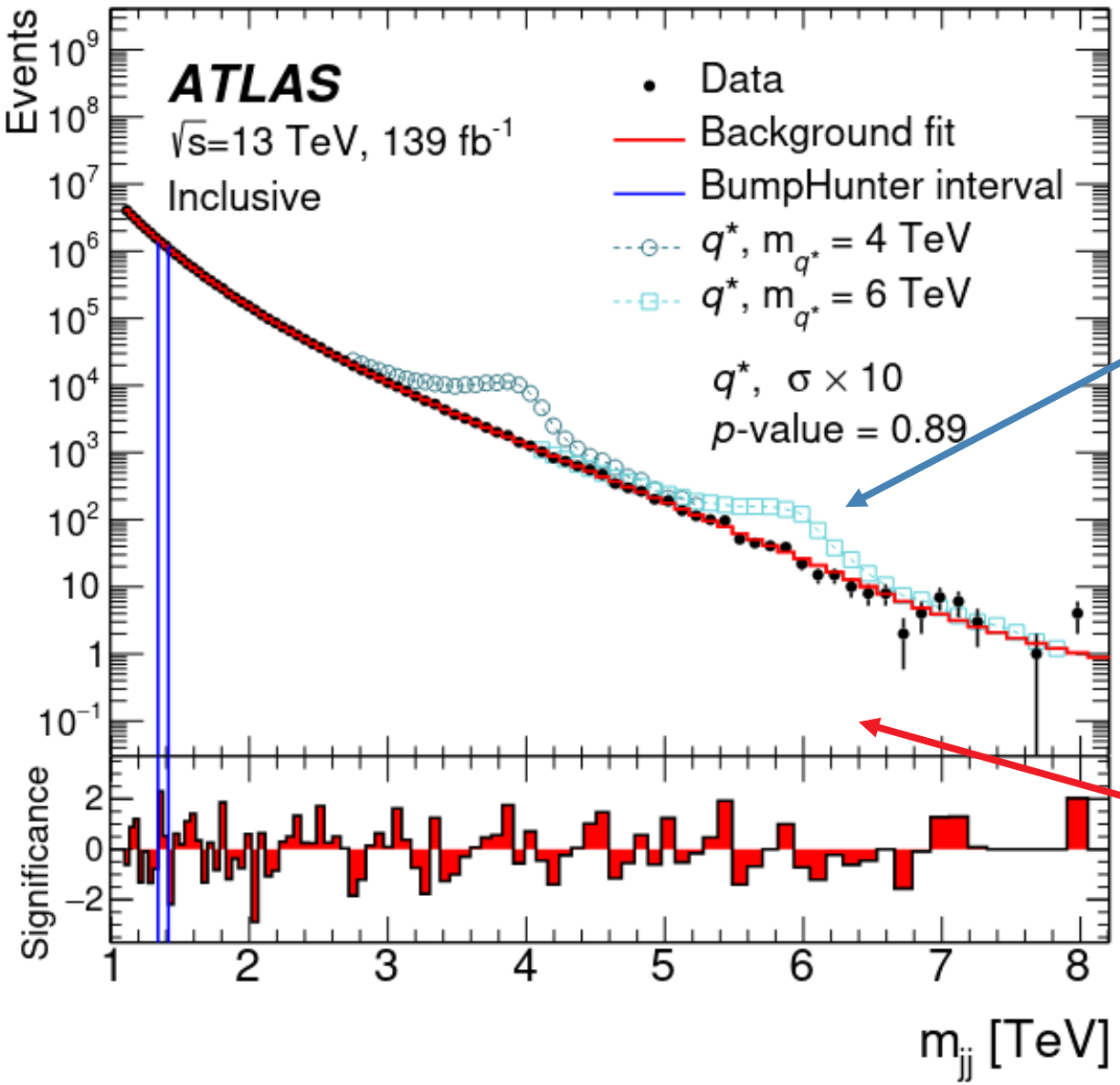
Calculate invariant mass



Does not require models predicting new particles

Поиски в инвариантных массах

ATLAS JHEP 03 (2020) 145
CMS JHEP 05 (2020) 033

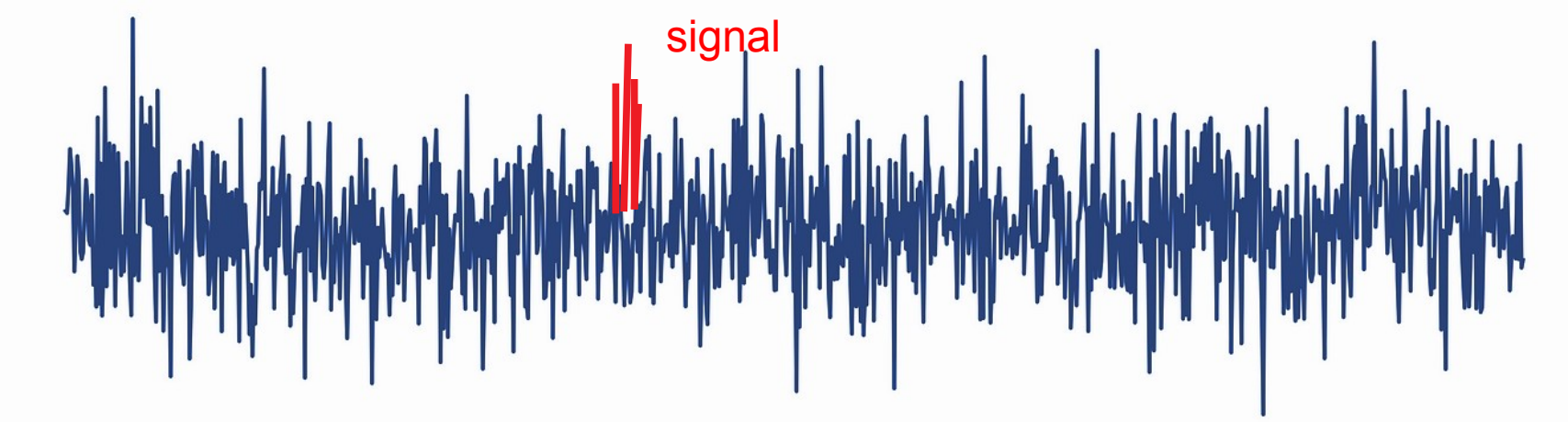


Hypothetical heavy particles

Standard Model events

$$f(x) = p_1 (1-x)^{p_2} x^{p_3 + p_4 \ln x + p_5 (\ln x)^2}$$

Стандартная модель как «шум»



➔ If there are “noise” and “signals”, one can do 2 things to identify “signals”:

(1) Design selections based on signal features and apply filters based on these features (traditional LHC searches)

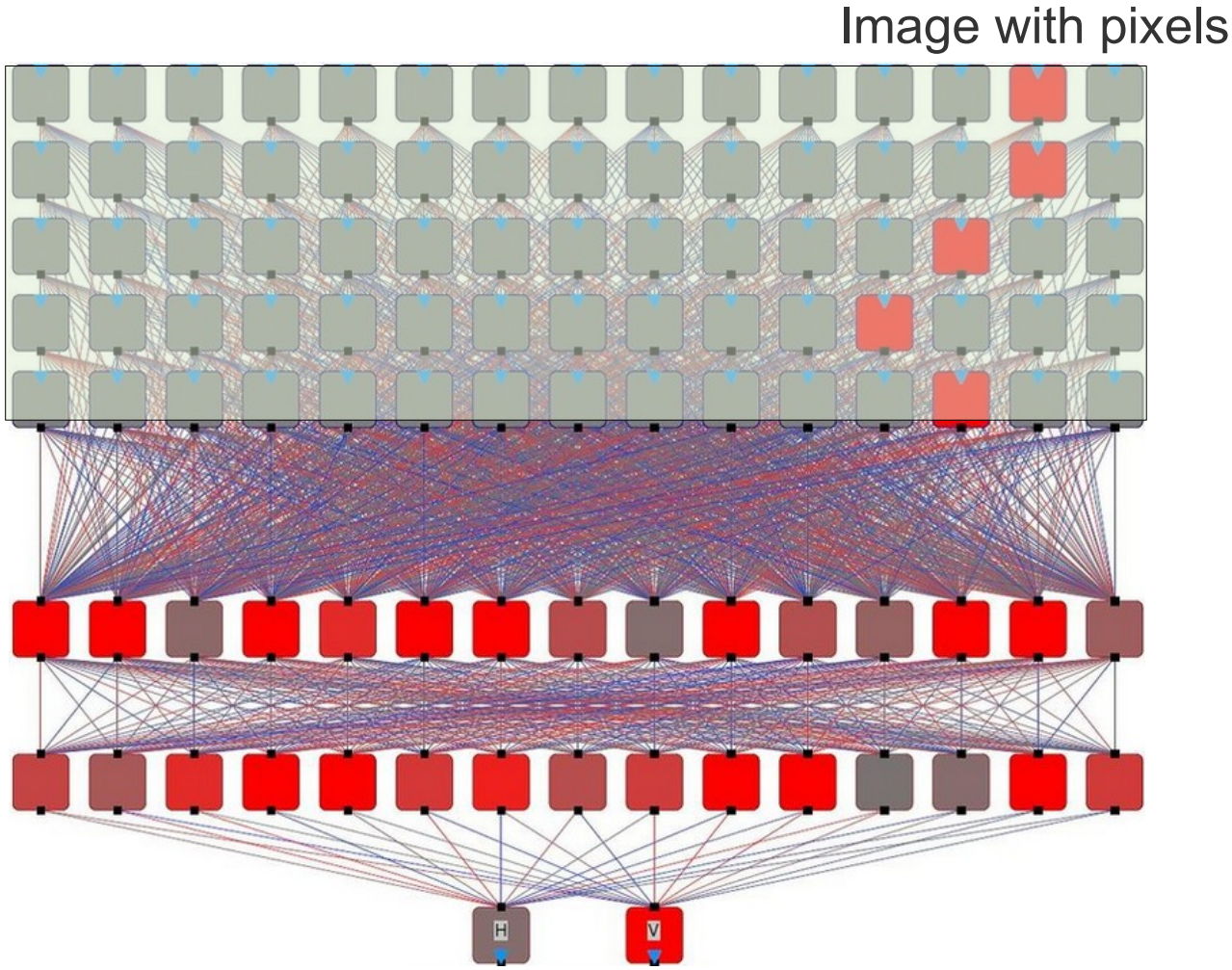
- Best we can do with MANY analysers!

(2) Design sections based on the knowledge of noise and filter out the noise

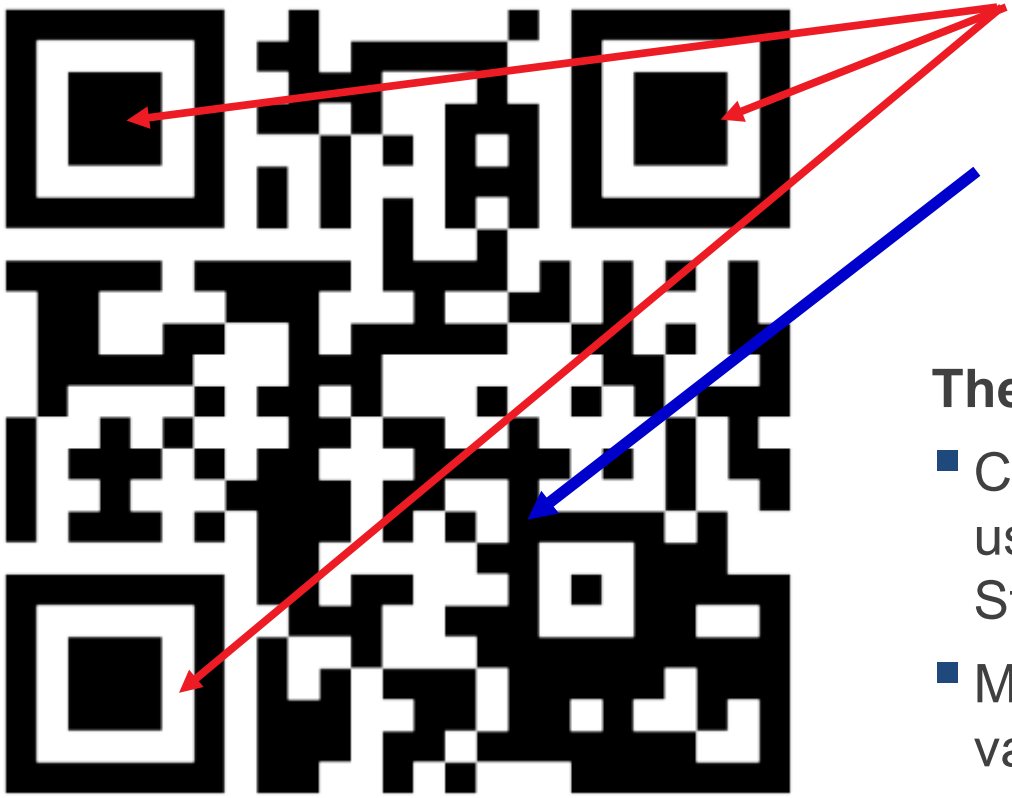
- Larger coverage of unexpected signatures

- Easy to use Machine Learning for anomaly detection when training on the noise

Использование нейронных сетей



QR codes for Machine Learning

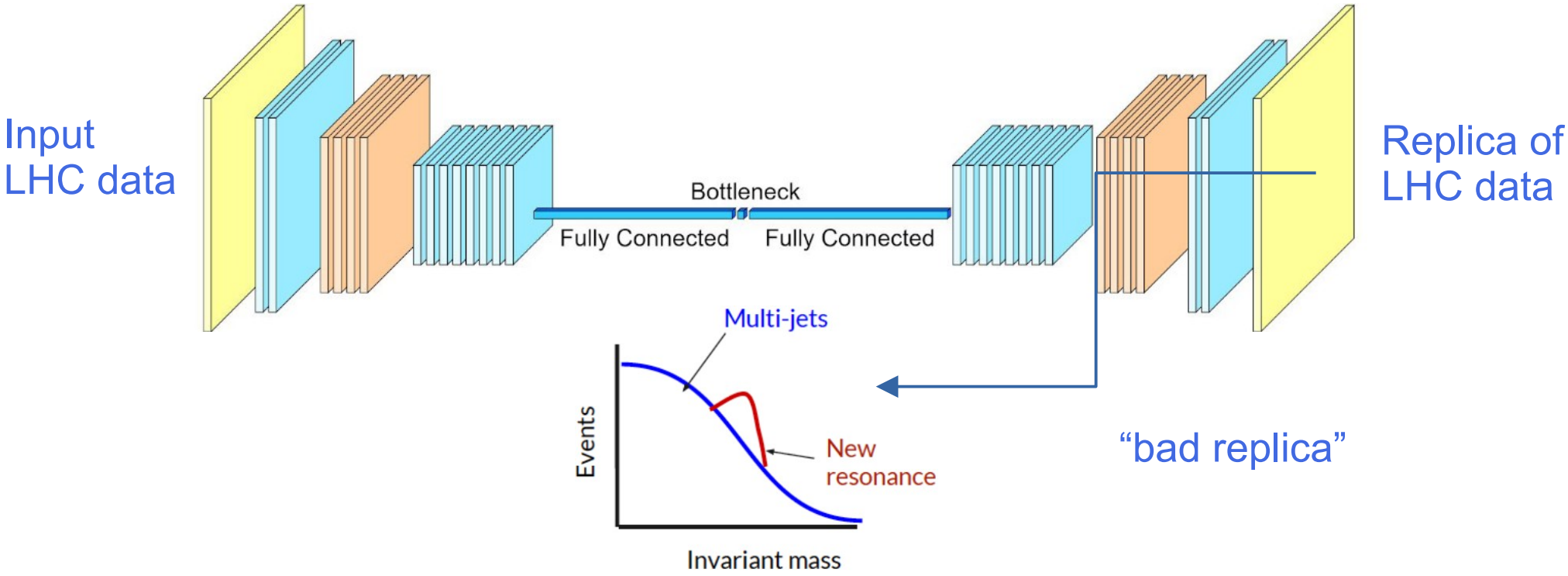


The idea:

- Convert each LHC event into “QR” code and use them for machine learning to remove Standard Model events
- Matrices are “Natural Language” than variable-sized lists of many particle types produced at the LHC

S. V. Chekanov, "Imaging particle collision data for event classification using machine learning", Nucl. Instrum. Meth. A, vol. 931, pp. 92, 2019

Новая концепция поисков на БАКе

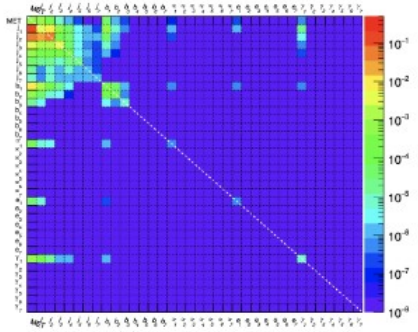


S. V. Chekanov, W. Hopkins, "Event-based anomaly detection for new physics searches at the LHC using machine learning", Universe 2022, 8(10), 494;

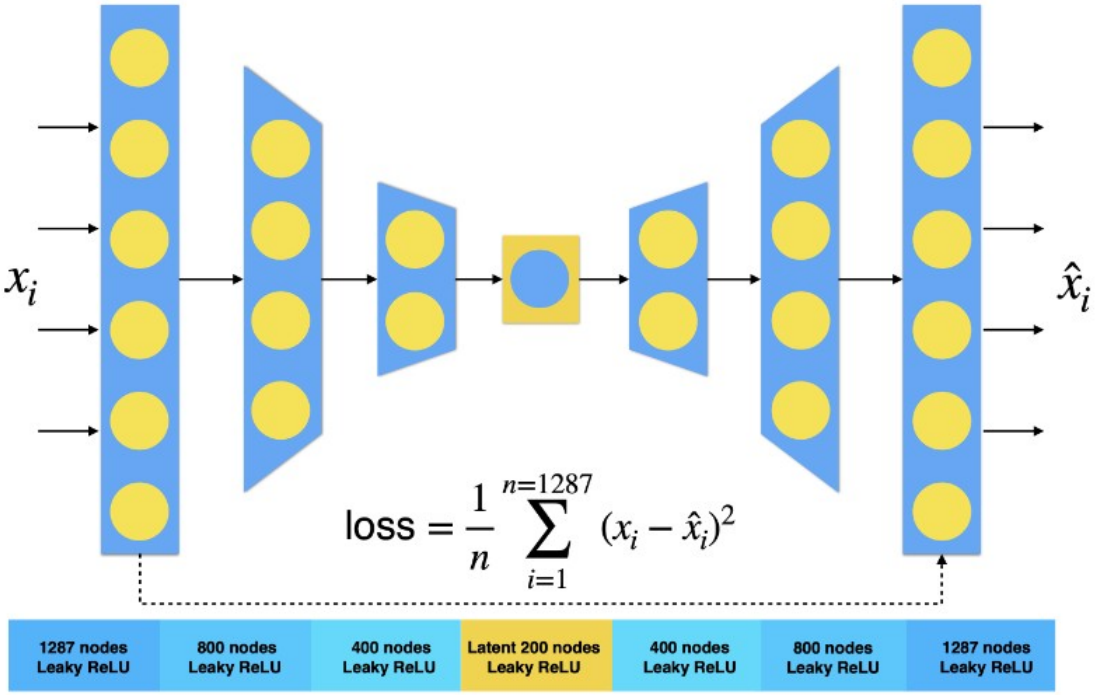
General searches using unsupervised machine learning

LHC event

Input
$36^2 - 9 = 1287$ variables

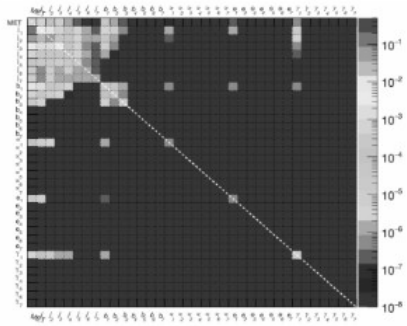


Autoencoder
(~ 2 million neurons)



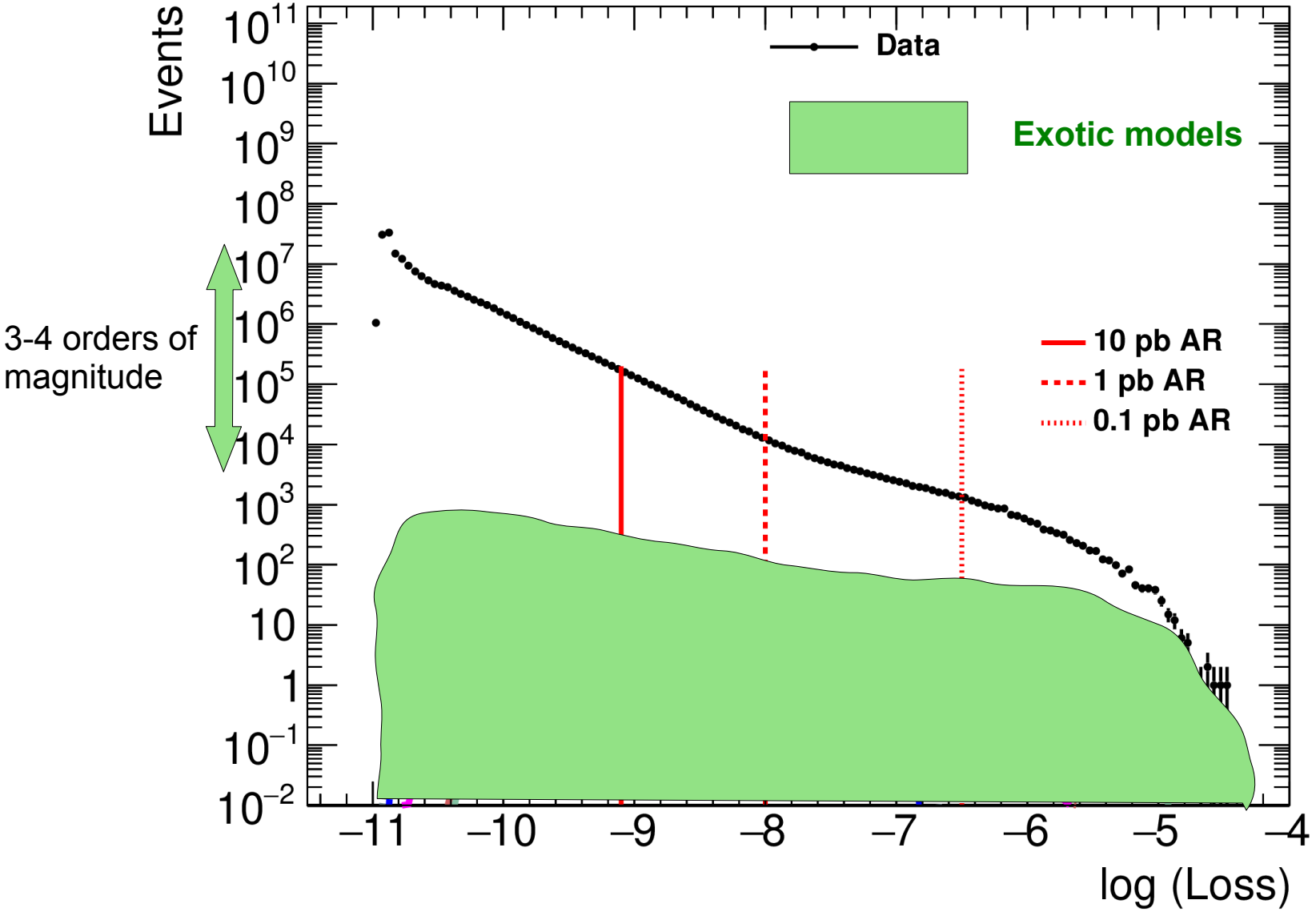
Reproduced

Output
1287 variables

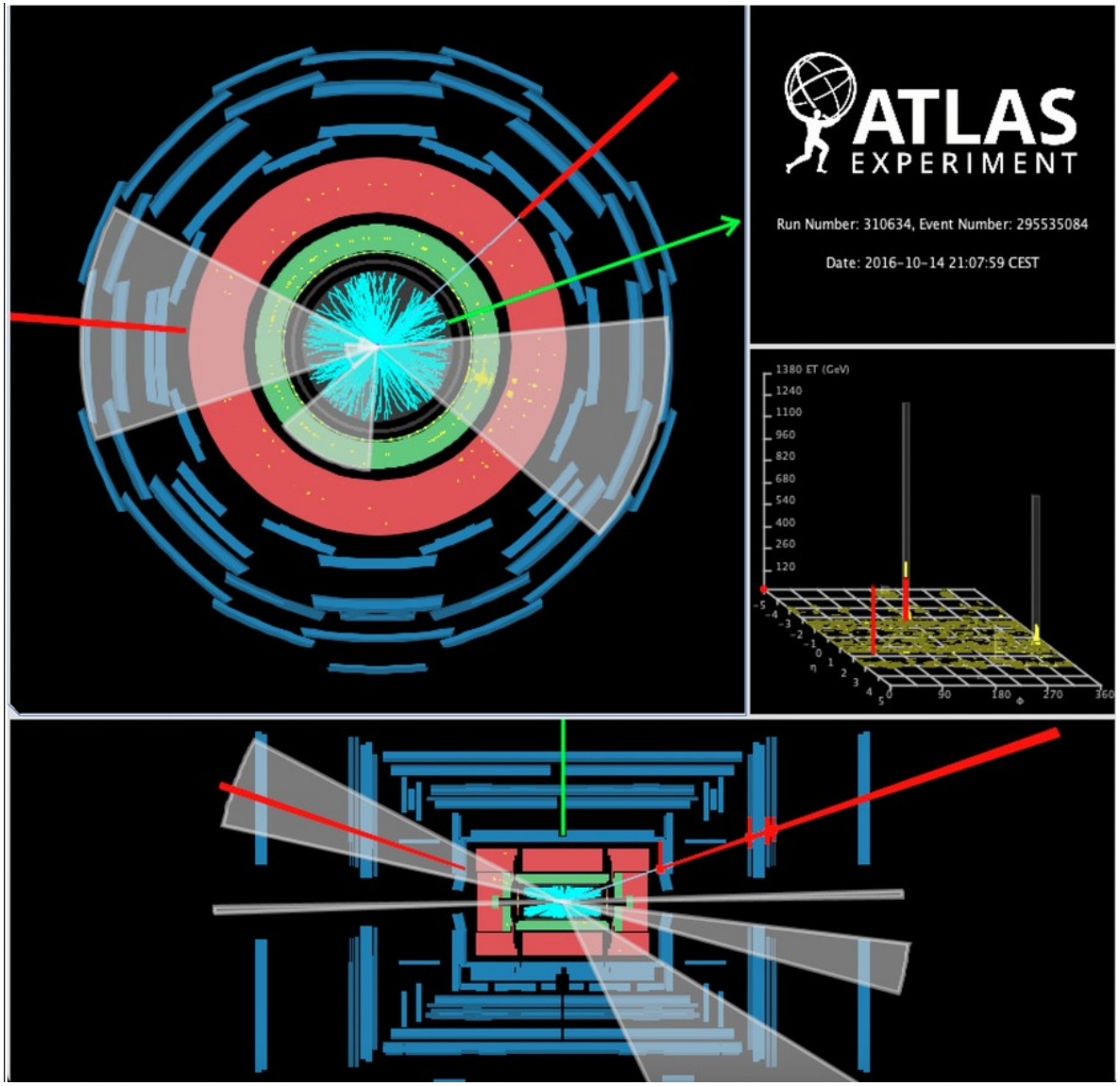


ATLAS Physics Briefings. https://atlas.cern/Updates/Briefing/Anomaly-Detection

General features (cartoon based on INT plot)



Typical event after AE for 4.8 TeV (largest deviation)



ATLAS Physics Briefings. https://atlas.cern/Updates/Briefing/Anomaly-Detection

Conclusions

- **Extensive program for searches for new heavy particles**
- **Refined studies with complex final state (jet, top, γ, $t\bar{t}$, W, Higgs, etc)**
- **Stay tuned: Ongoing analysis using Run 3 data**
  - 13 TeV → 13.6 TeV CM energy
  - Increase in luminosity (x 2 → larger statistics!)
  - Recent paradigm shift: **using AI for new physics searches**