UC SANTA CRUZ

CERN

PARTICLE ~~PARTY CALL~~ PHYSICS

nā mea hiki a me nā mea hoʻohālikelike

Dr. Giordon Stark
Koloka

Ianuali 9th 2025

giordonstark.com

ATLAS EXPERIMENT

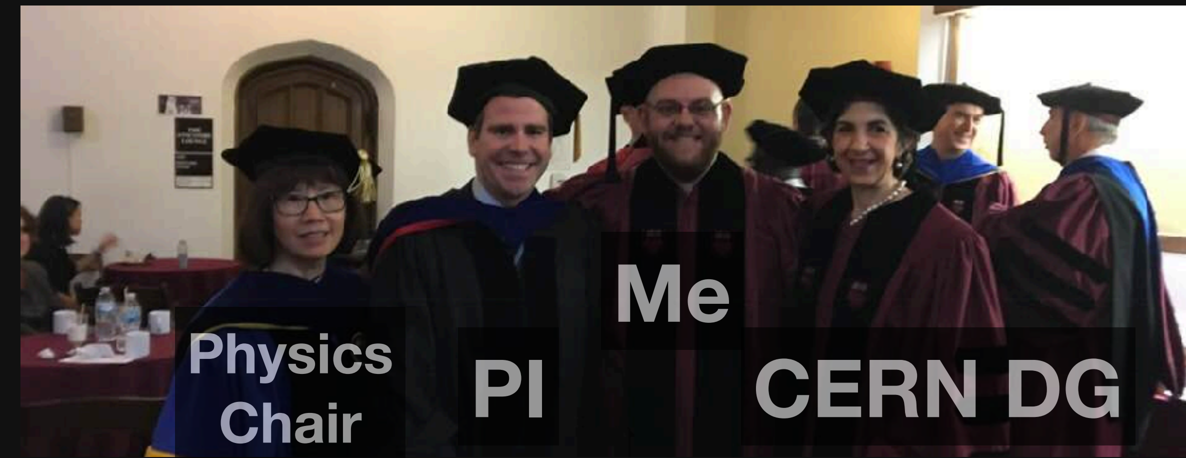
Run: 300800

Event: 2418777995

2016-06-04 03:47:03

if you can read this, you're too close

About Me



- B.S Caltech 2012 (LIGO)
  - Brownian Thermal Noise
- PhD UChicago 2014-2018 (ATLAS)
  - Search for new (hadronic) physics and instrumentation upgrades (hardware filtering)
- Currently project scientist at SCIPP, UC Santa Cruz since 2024 (postdoc from 2018-2024)
  - Search for new (electroweak) physics, large-scale physics analysis combinations, Standard Model measurements, software development, and instrumentation upgrades
- Lots of outreach/teaching/DEI experience (bootcamps, workshops, committees)

Overview of Today

The long road to making (accessible) physics
(and how rocky it has been at times)

- The Standard Model… and **beyond**!
- The Large Hadron Collider, **ATLAS**, and you
- Searching for signs of **new physics**
- Experimentalist introduction to **statistics, hypothesis testing**
- **Accessibility** in physics education
- What does the **future** have in store for us?

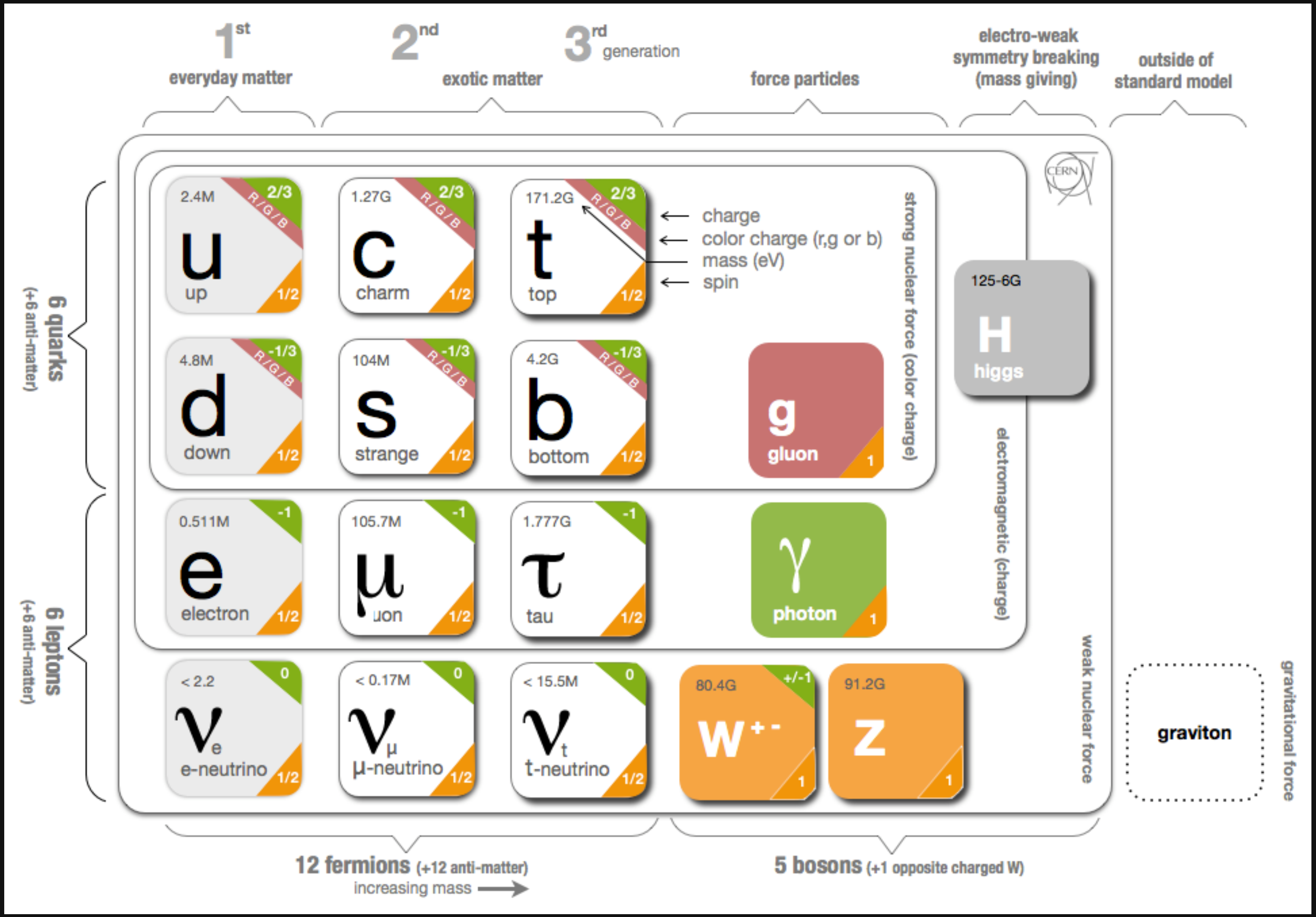
⌛ **Let's get started**

The Standard Model

A study of particles and their interactions

"The story so far: In the beginning the Universe was created. This has made a lot of people very angry and been widely regarded as a bad move." — Douglas Adams

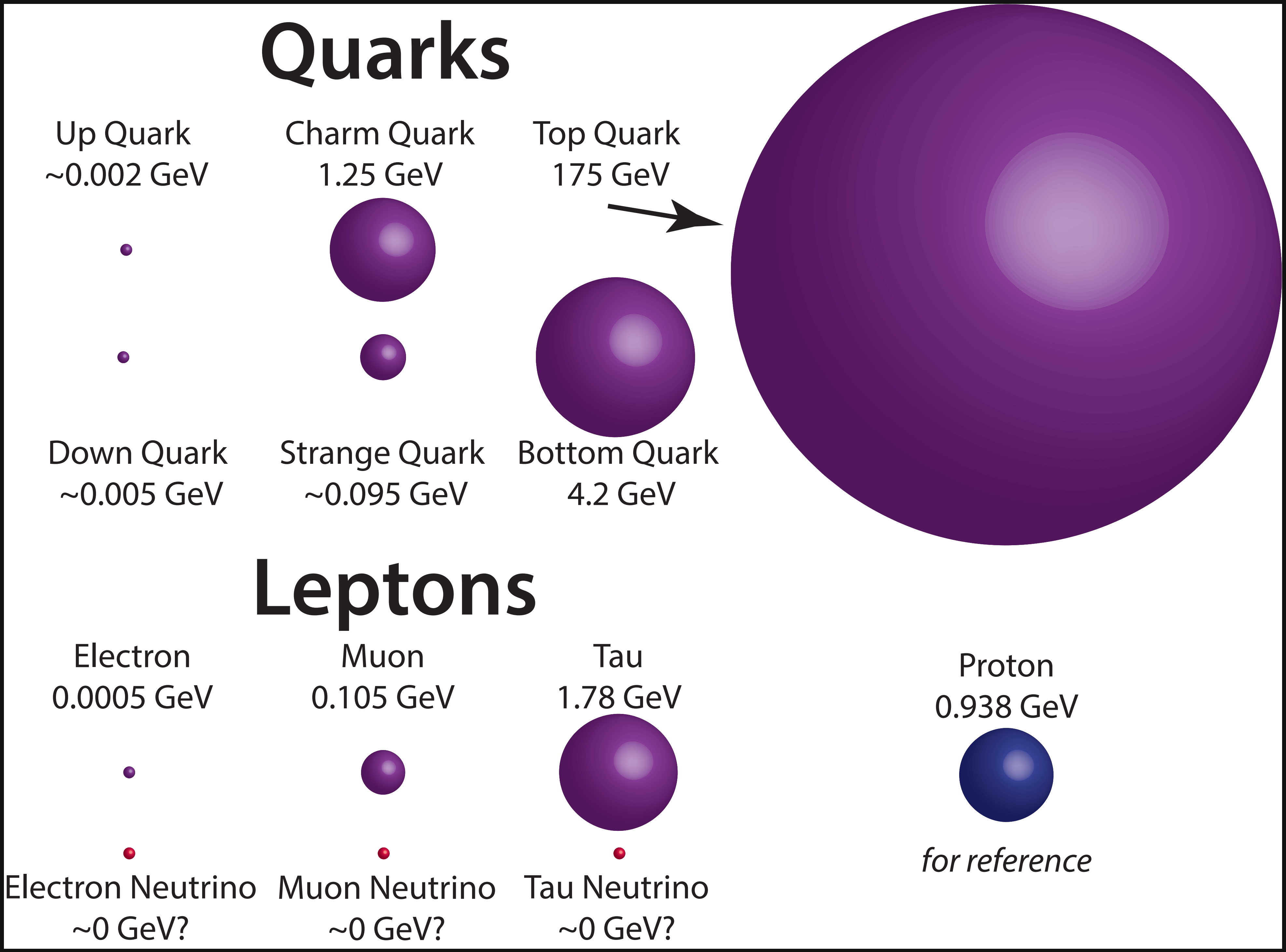
Periodic Table of Particles



12 fermions
(6 leptons, 6 quarks)
half-spins $(\frac{1}{2}, \frac{3}{2}, \ldots)$

5 bosons
(4(?) force-carriers)
integer spins $(0, 1, 2, \ldots)$

An Alternative Perspective

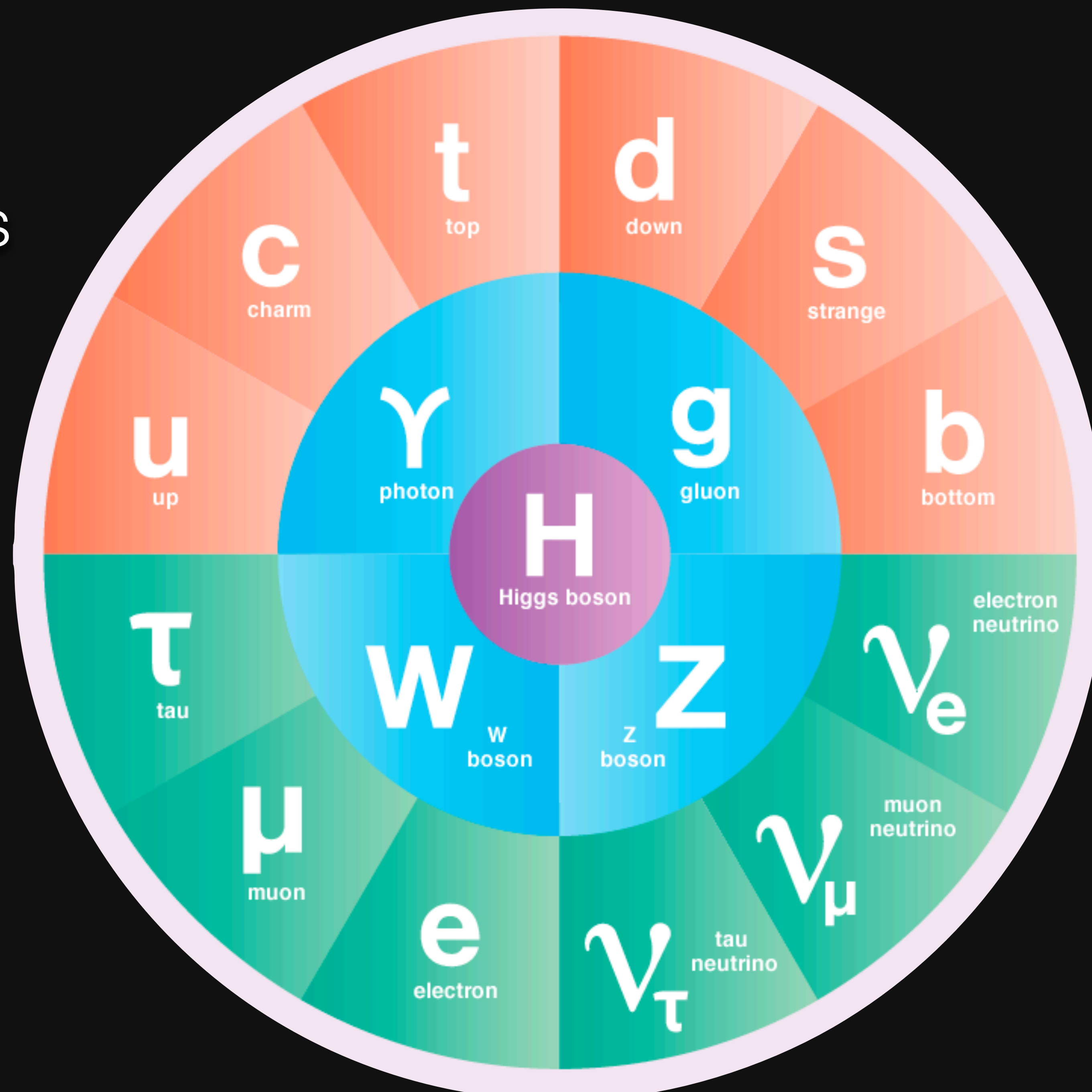


Volume proportional to the mass

https://www.symmetrymagazine.org/standard-model/

Pieces of the puzzle

- We observe these particles in nature and make measurements
- The Standard Model is a theory
  - *Best attempt to make sense of the chaos*
- **Not complete!** We don't know what's missing.
  - Gravity?
  - Dark Matter?



QUARKS LEPTONS BOSONS HIGGS BOSON

Beyond the Standard Model

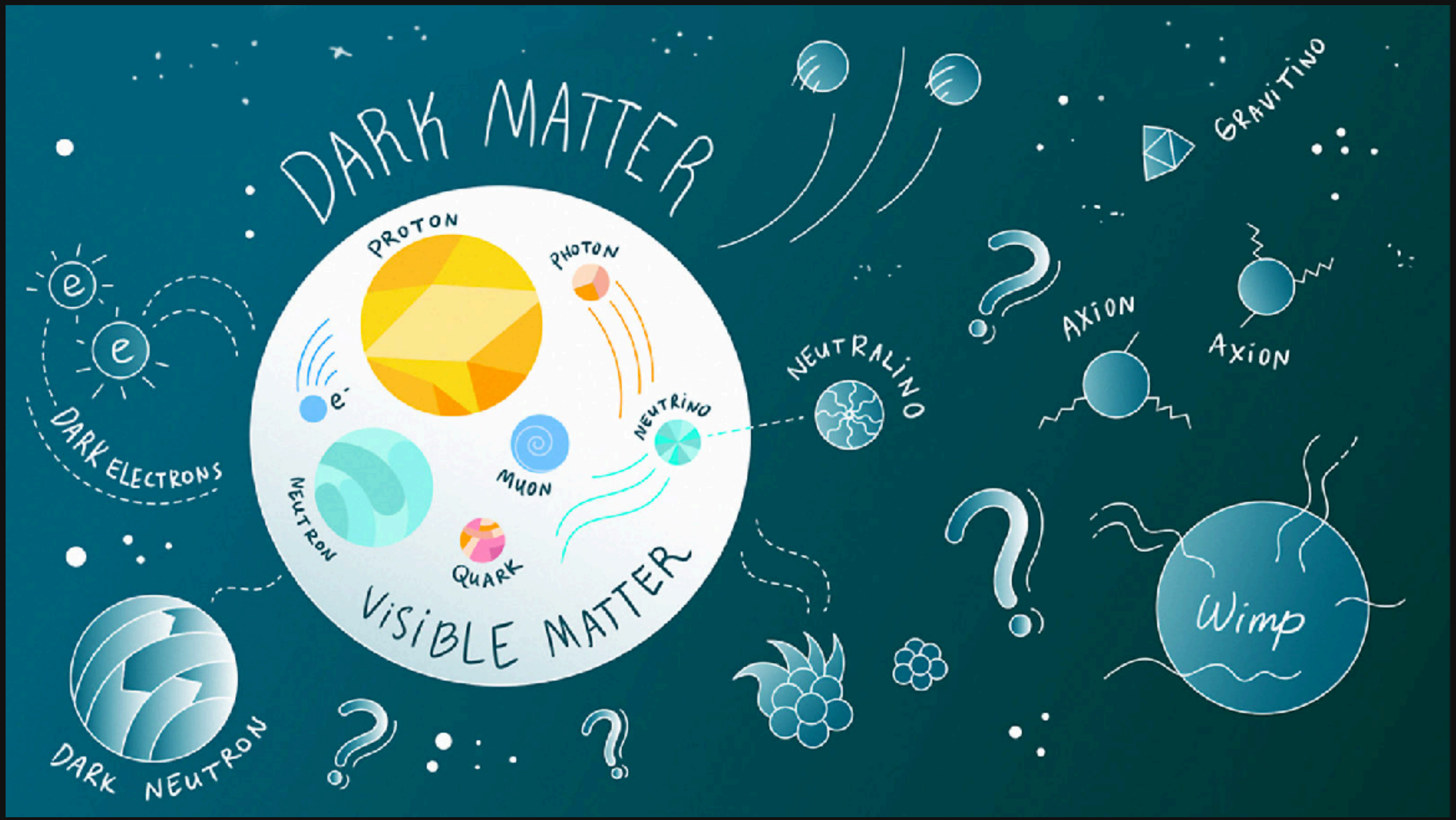
What *is* dark matter?

Where did all the antimatter go?

Why does the standard model look the way it does?

Why is the weak force so much stronger than gravity? (Hierarchy problem)

Supersymmetry (SUSY)
framework with robust theoretical motivations theorists use to explore new physics ideas



❗ SUSY provides benchmark models, for experimental physicists like me, to help answer these questions!

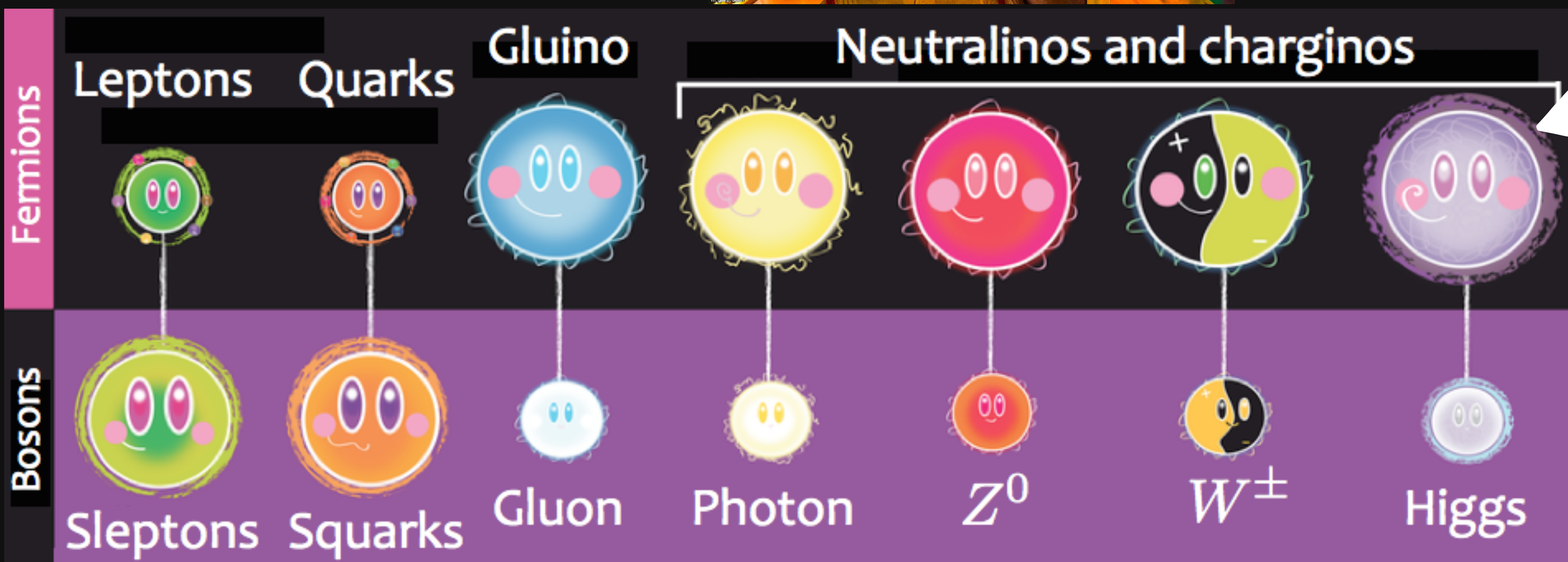
What is supersymmetry?

small = Standard Model
large = Beyond the SM

Higgsinos

$\frac{N}{2}$

N

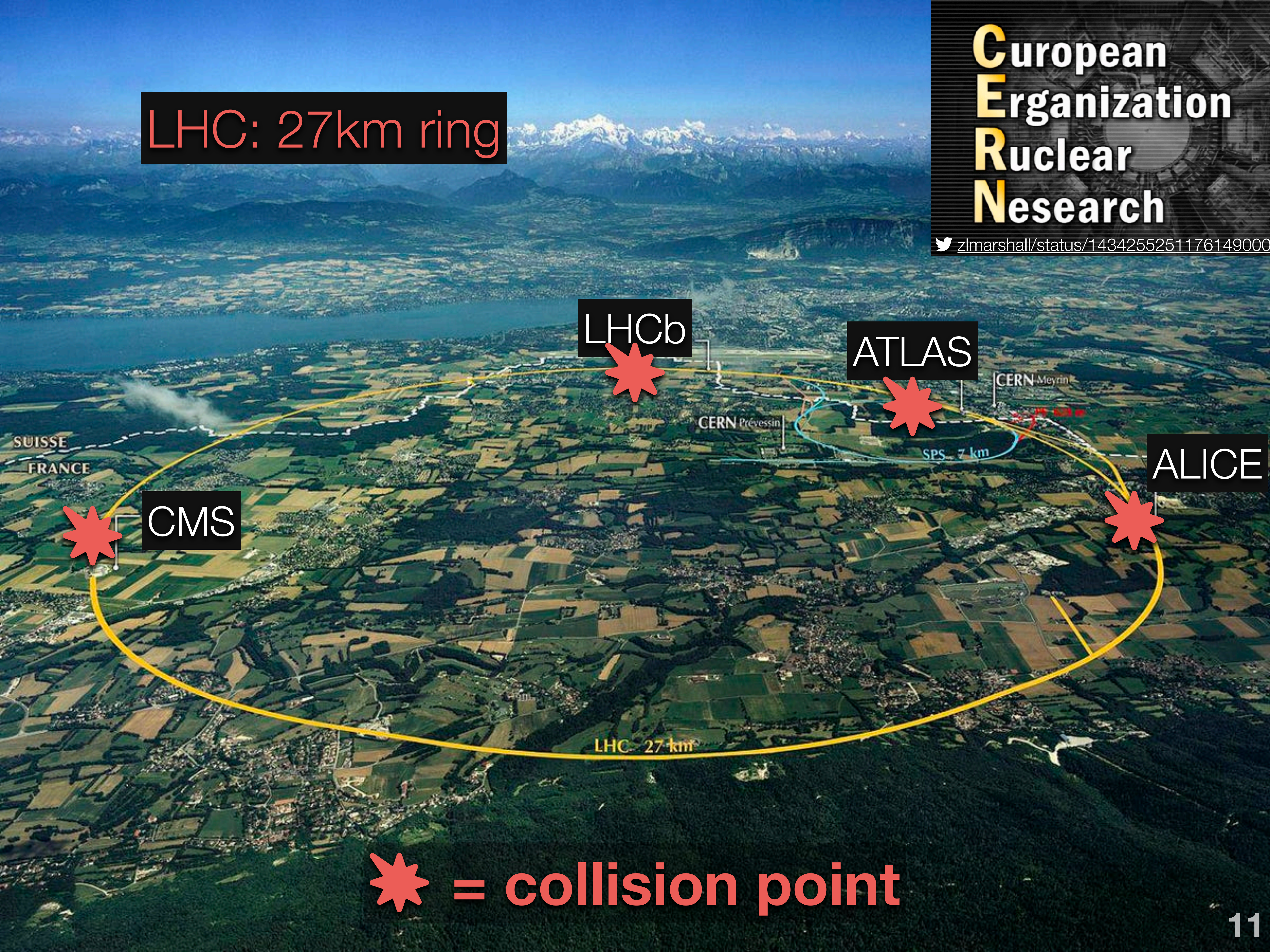


A particle physics tango between fermions and bosons

The ATLAS Detector

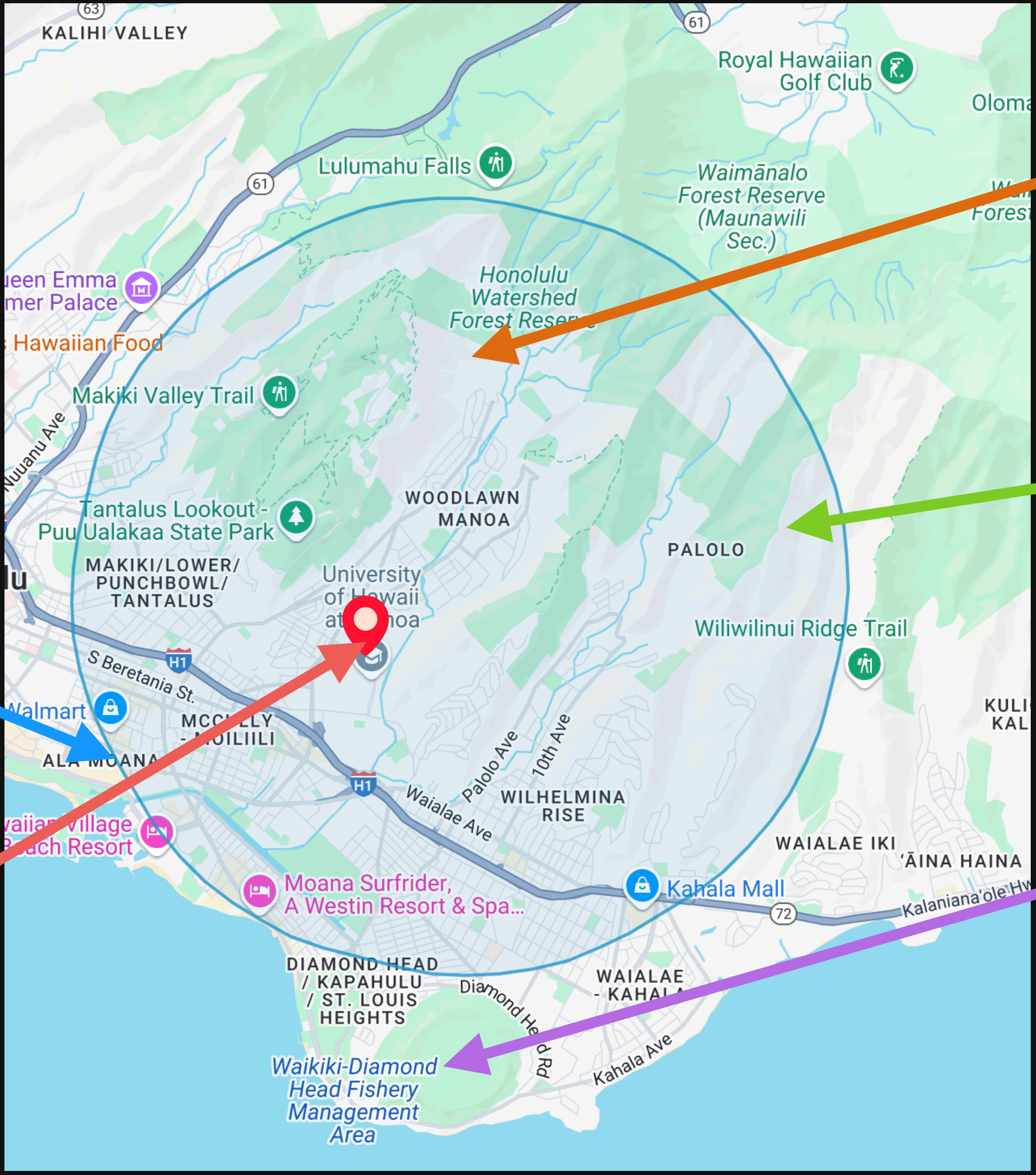
Taking pictures of proton-proton collisions

"The single most important component of a camera is the twelve inches behind it." — Ansel Adams


LHC: 27km ring
Curopean
Erganization
Ruclear
Nesearch
zlmarshall/status/1434255251176149000
LHCb
ATLAS
ALICE
CMS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
LHC 27 km
= collision point

https://howlargeisthelhc.com/#/

Just how big is the LHC?



Lyon Arboretum

Palolo

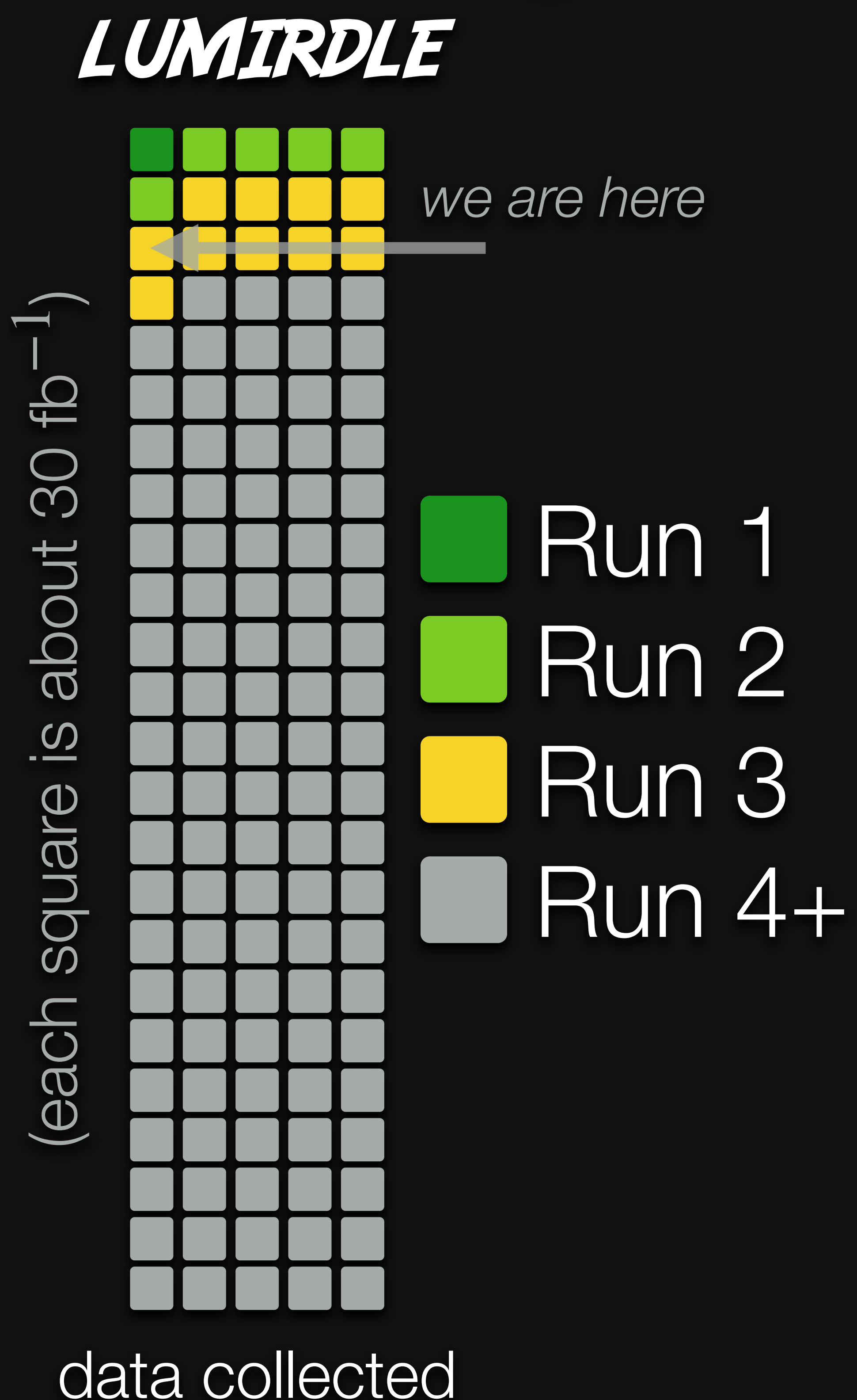
Ala Moana

Diamond Head

This talk

Every second, protons make ~12,000 trips!

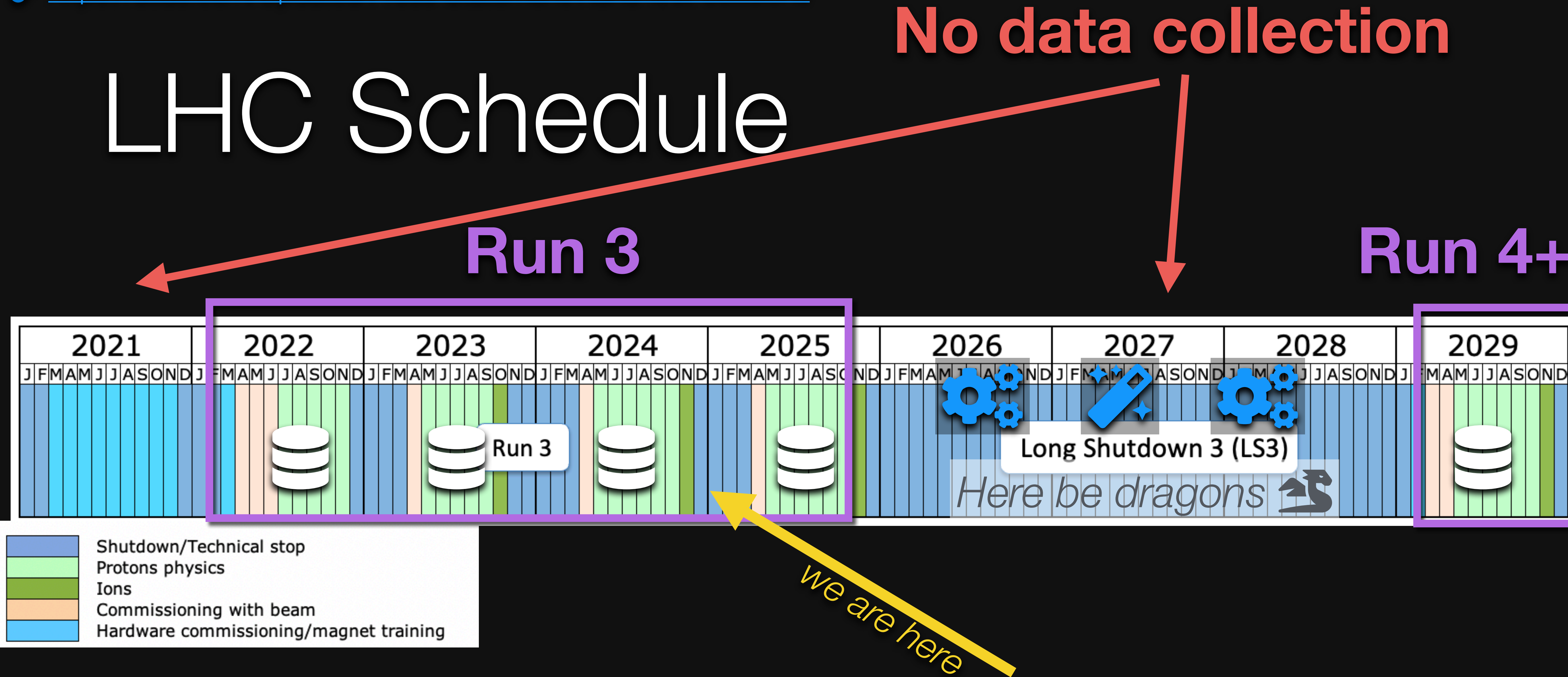
The Large Hadron Collider



- ~**20 more years** of (HL-)LHC physics
- In 2015-2018: collected 5x more data than in the dataset where we discovered the Higgs
  - 40 million collisions per second (one every **25 ns**)
  - 90 petabytes/year of data

https://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-long-term.htm
https://atlas.cern/Updates/Press-Statement/Run3-first-collisions

LHC Schedule



Experiments started up again 2.5 years ago, **Run 3 data** July 5th 2022!

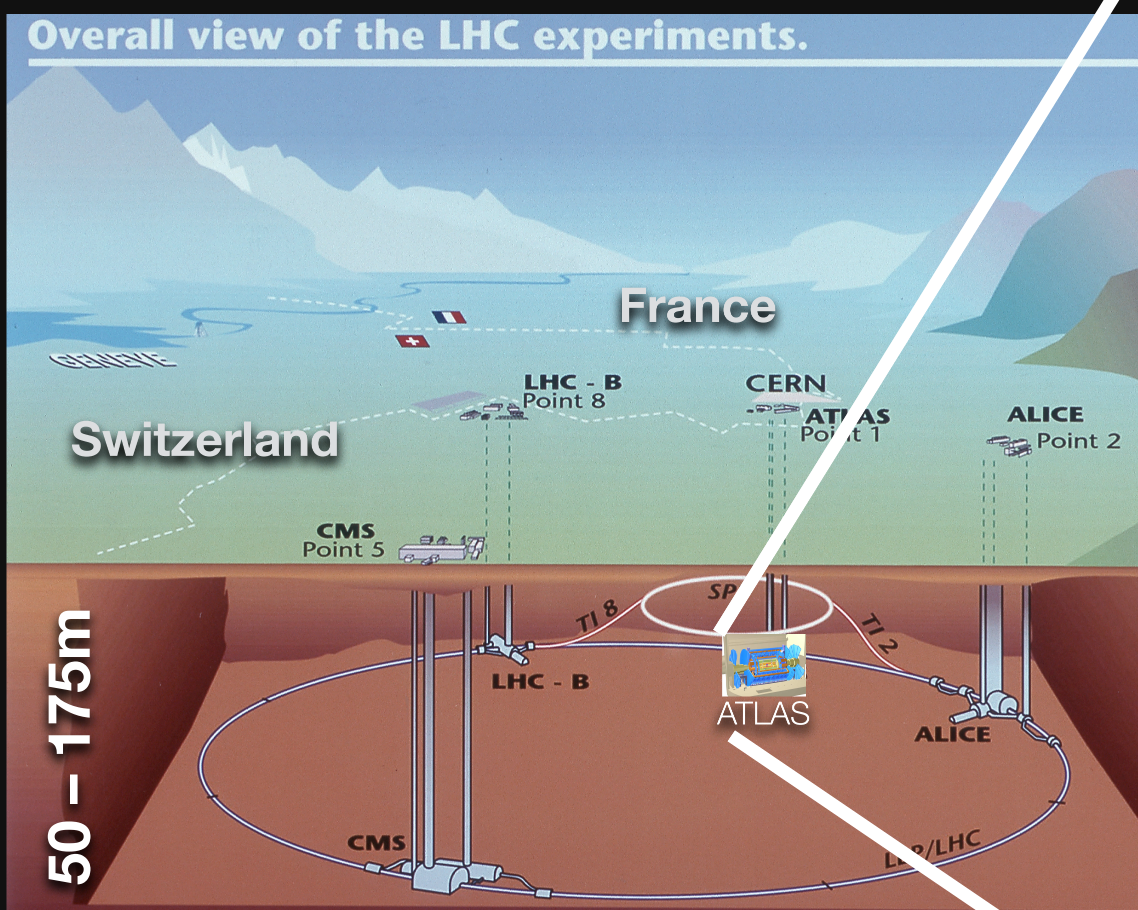
- Focus on “doing more with what we have"
  - clever techniques to find new physics (SUSY?) in existing data
  - **global fits and large scale combinations to determine future directions**
- **Finalized calibrations** on physics objects (electrons, muons, jets, photons) and pushed **object definitions to lower energies**

A collider and a detector

Large Hadron Collider

27 km collider, operational since Sept. 2008

Four points where proton-proton beams cross

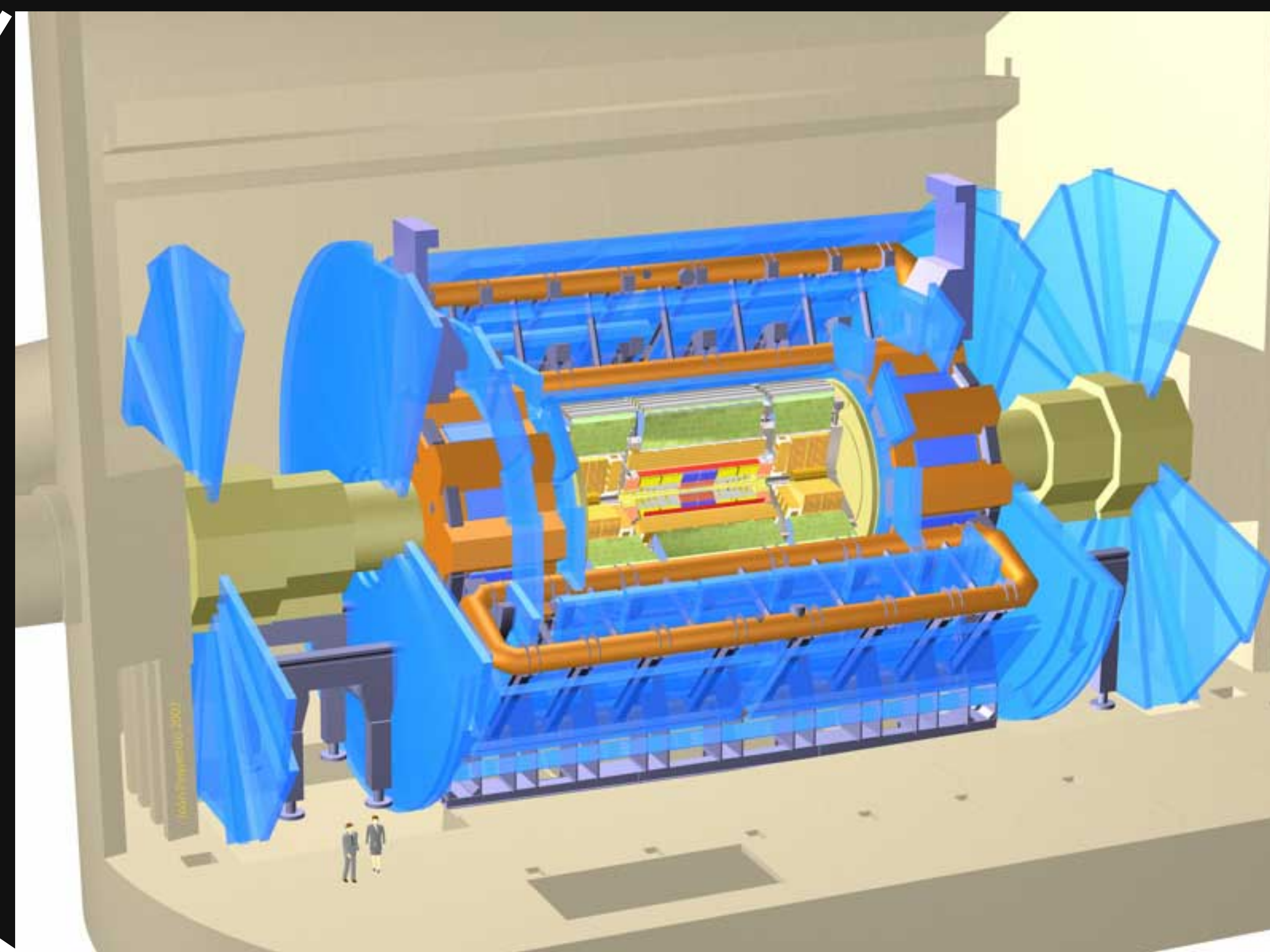


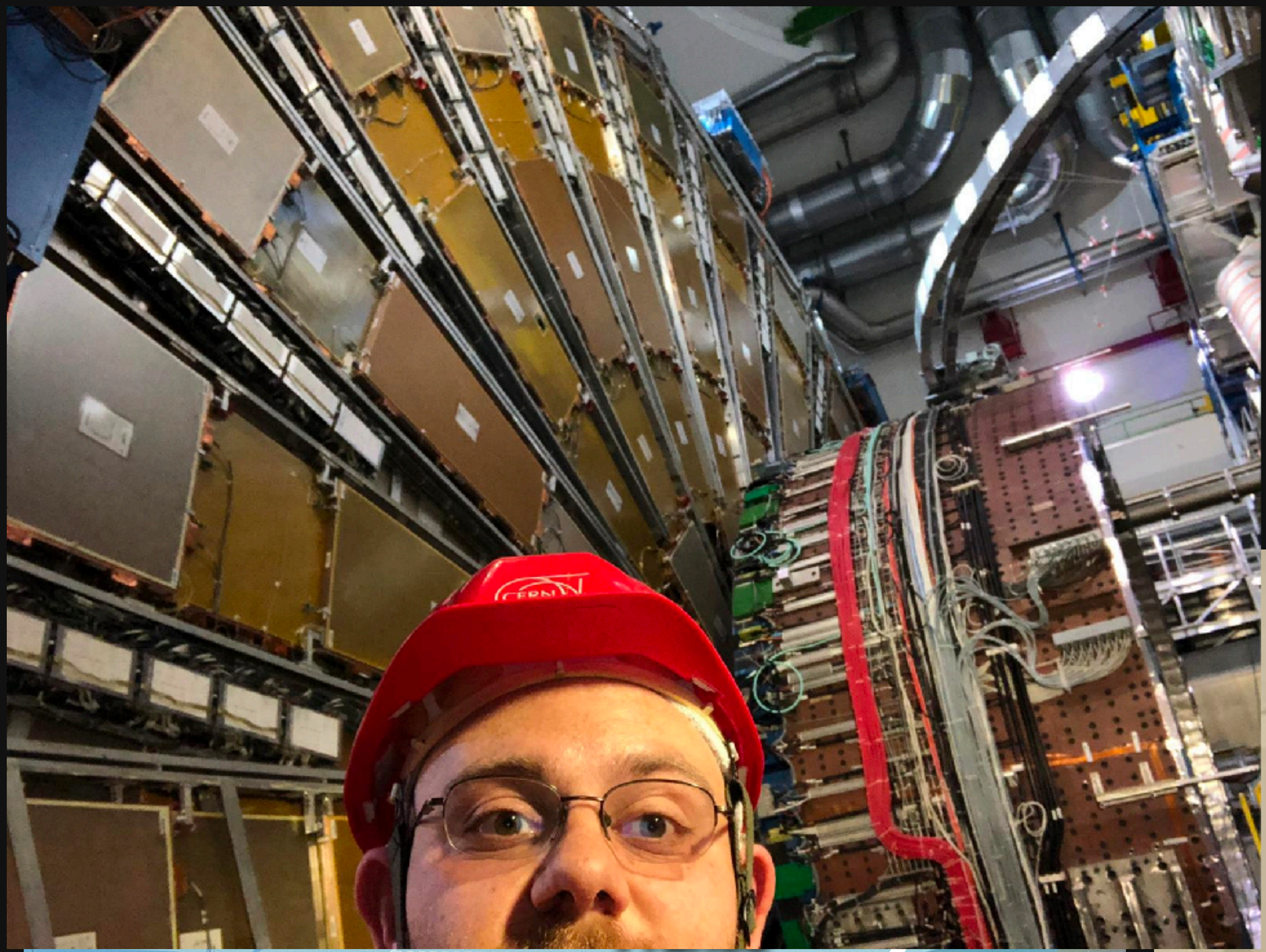
Stable rock at that depth

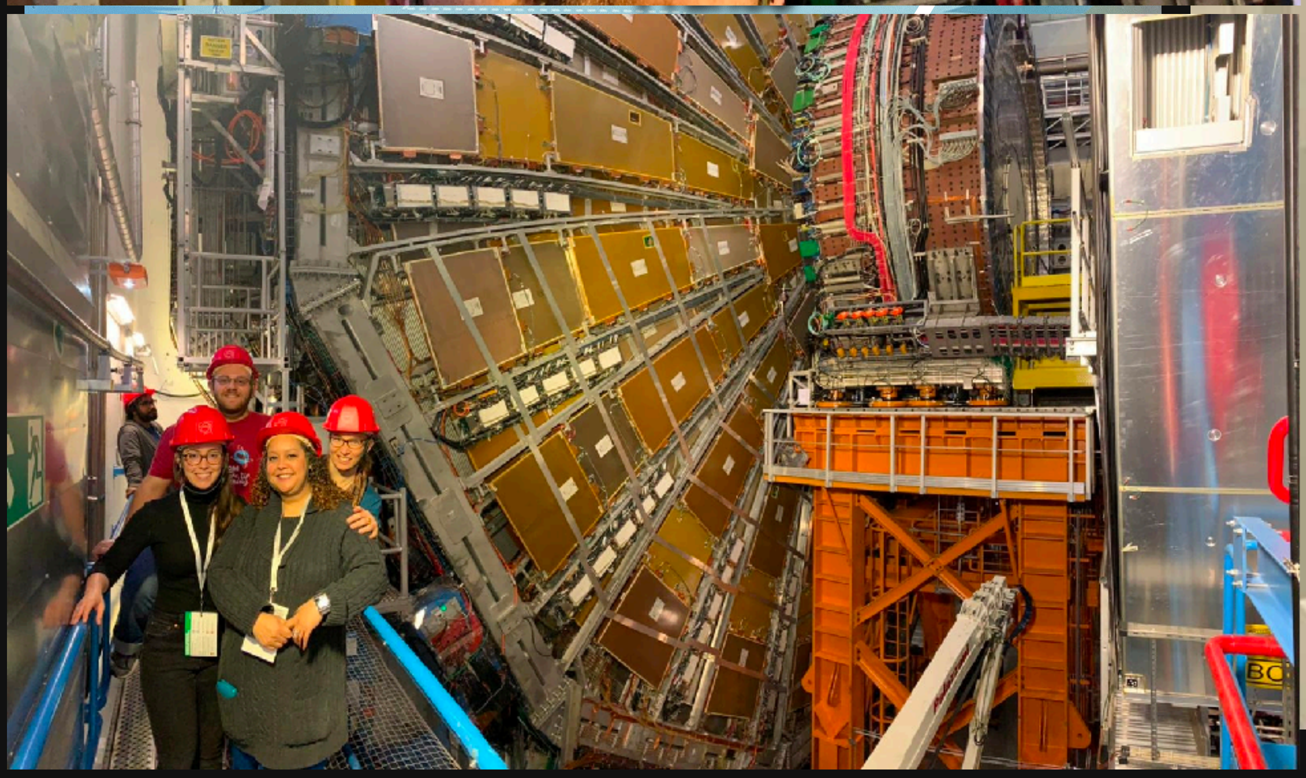
ATLAS

7000 ton detector (46m x 25m)

Located at collision Point 1





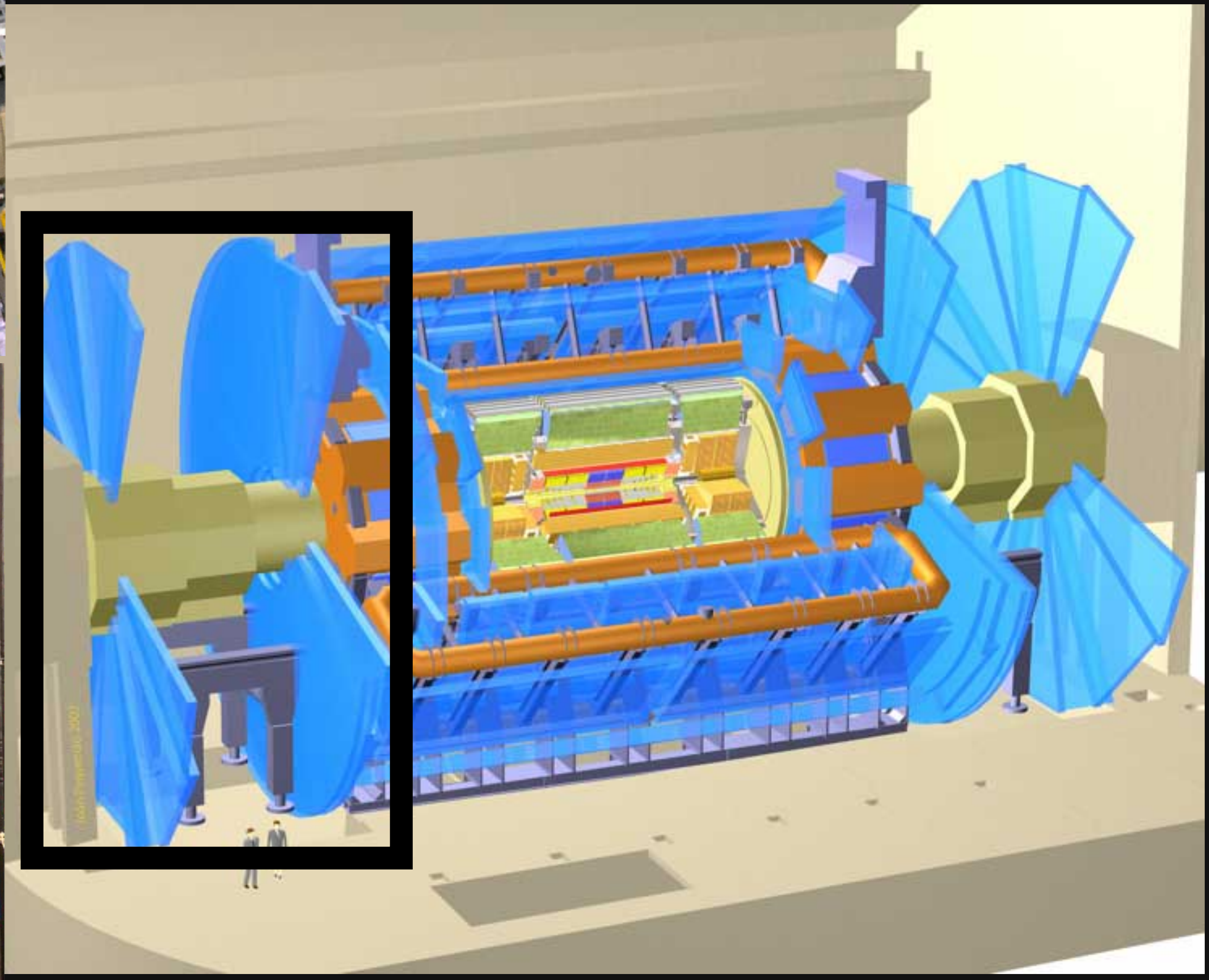


a detector

ATLAS

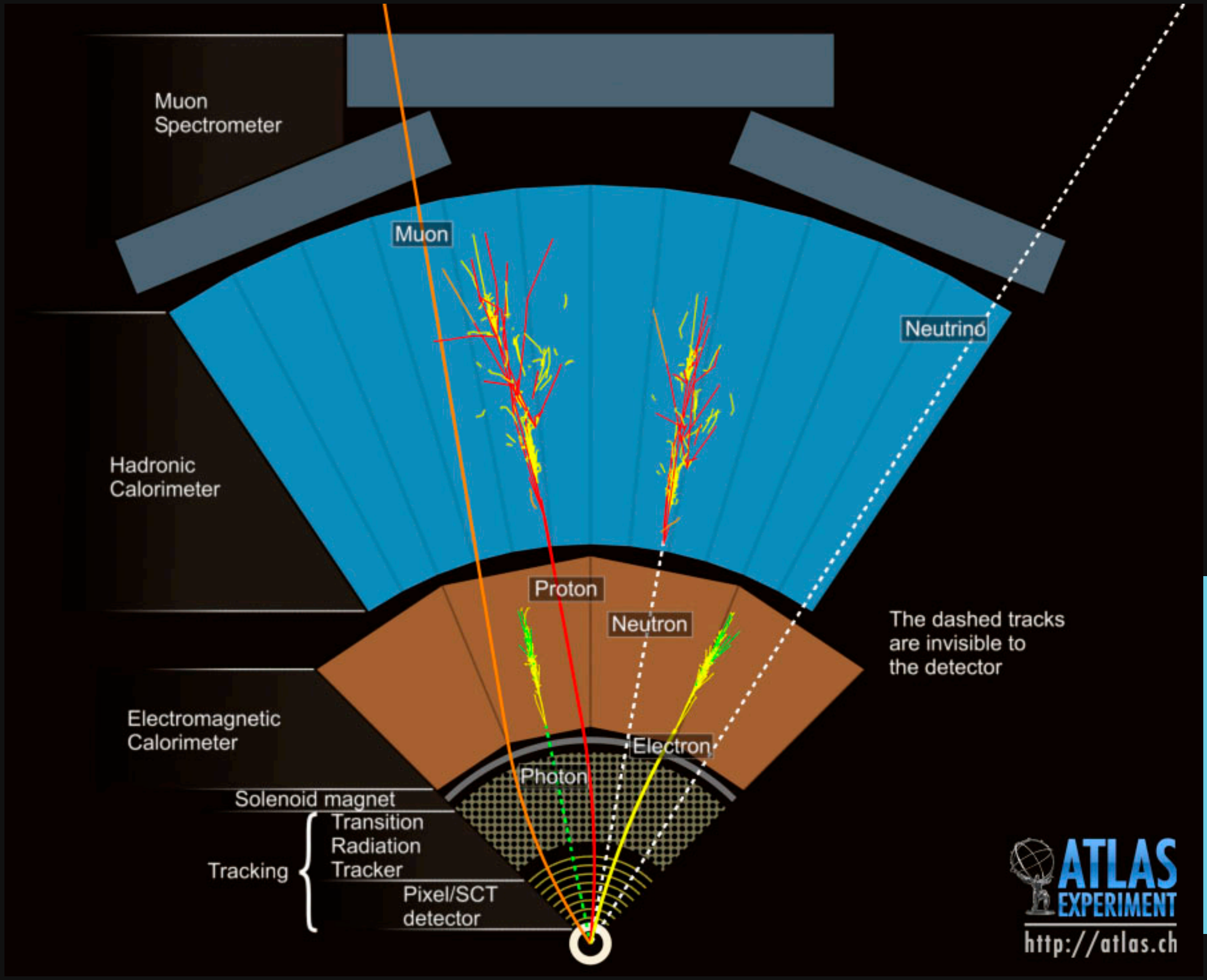
7000 ton detector (46m x 25m)

Located at collision Point 1

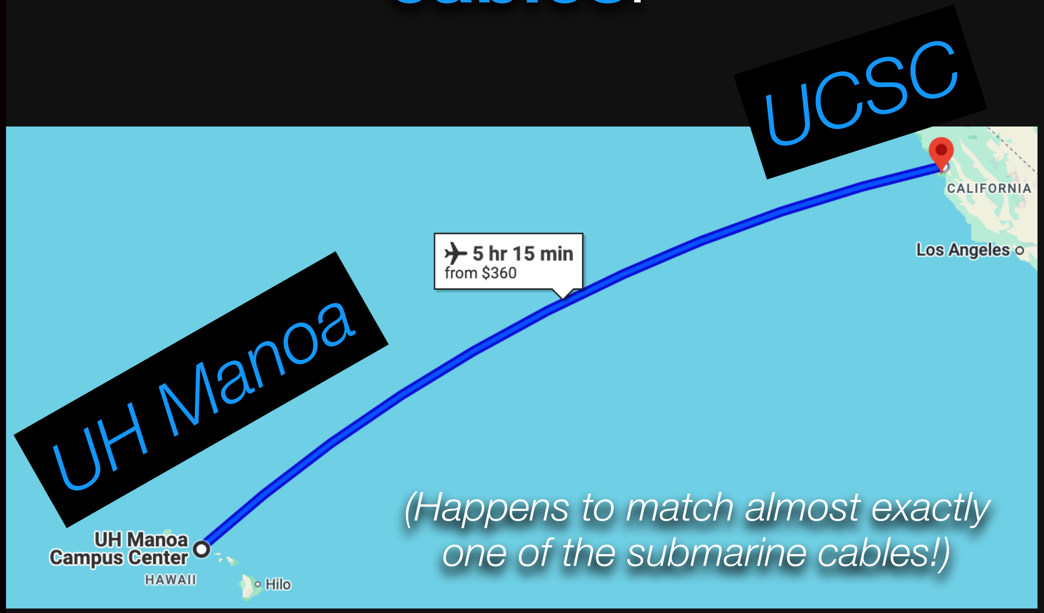


The ATLAS Detector

4 main subsystems: inner detector, muon spectrometer, calorimetery, and trigger

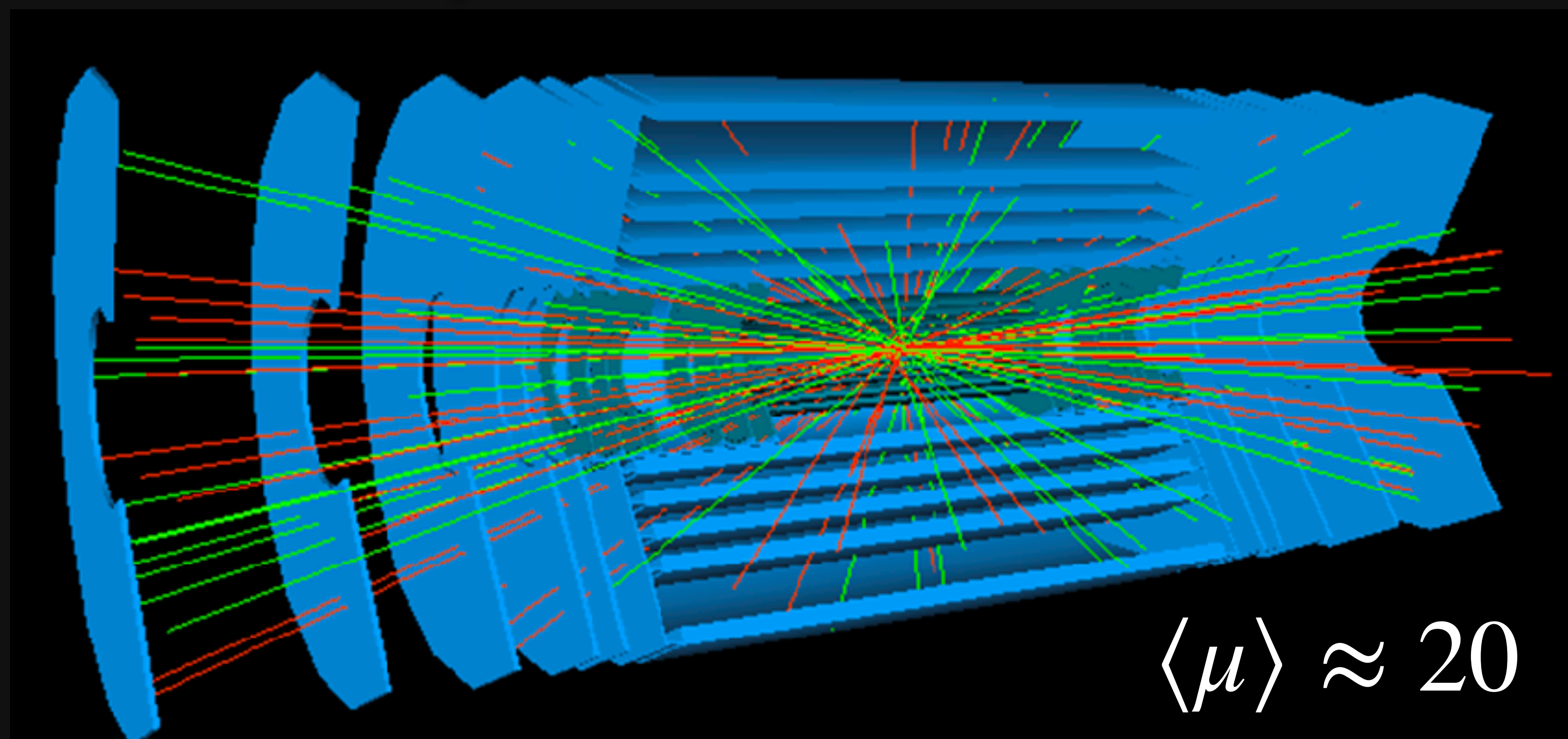


A single complex detector compromising many subsystems.
Over 100 million electronic channels and **3000km of cables**!

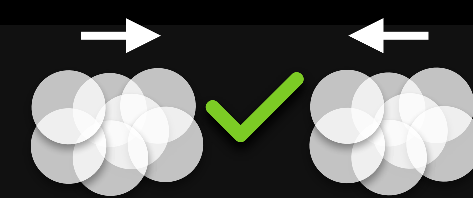


$\langle \mu \rangle$ = *number of simultaneous collisions*

An event (multi collisions!)



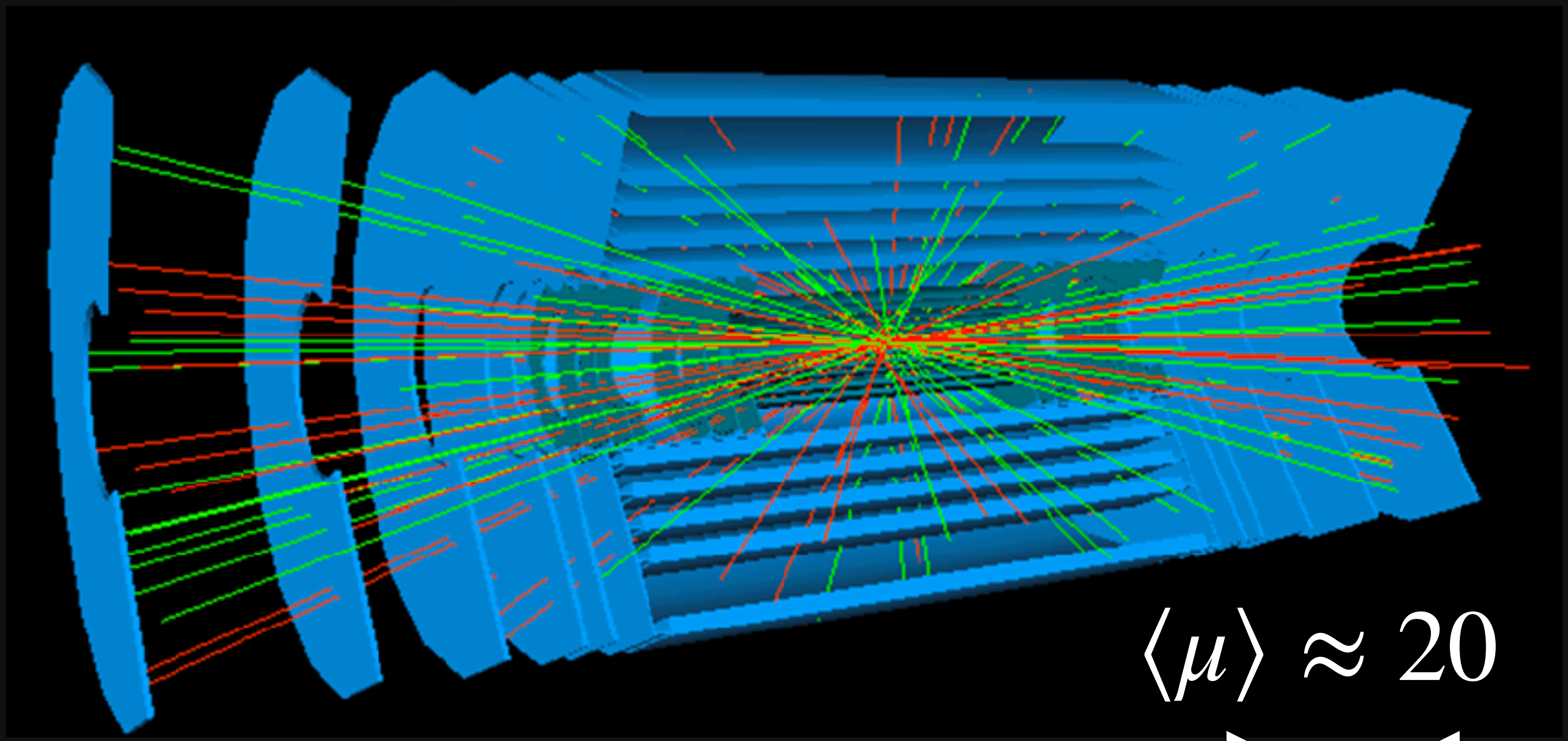
colliding two protons: difficult

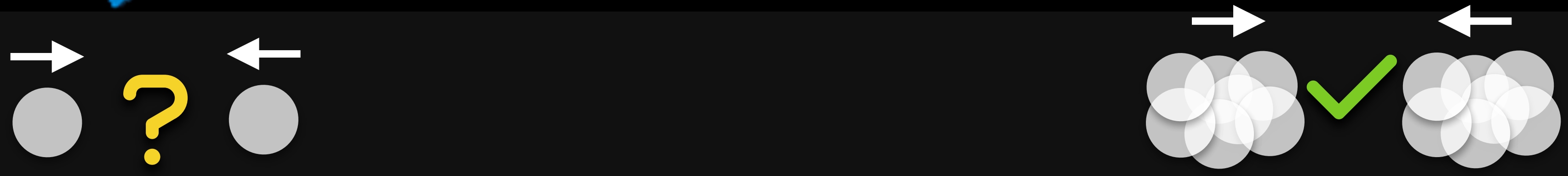


colliding billions: easier

$\langle \mu \rangle$ = *number of simultaneous collisions*

An event (multi collisions!)





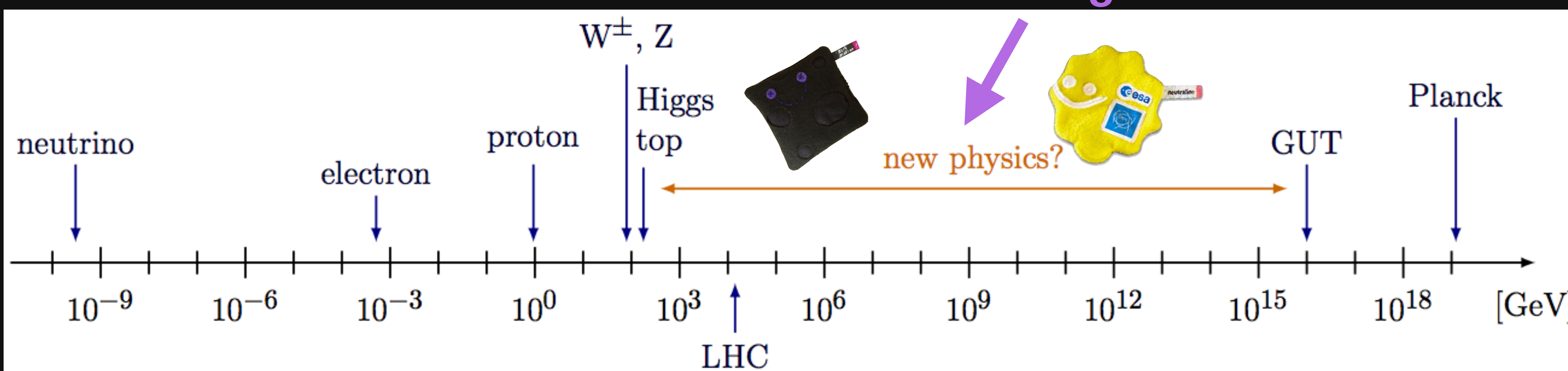
colliding two protons: difficult

colliding billions: easier

⚠️ Drawback: need to *efficiently* identify the **hard collision** amongst the "**noise**"

Searching for SUSY

Where is SUSY hiding?

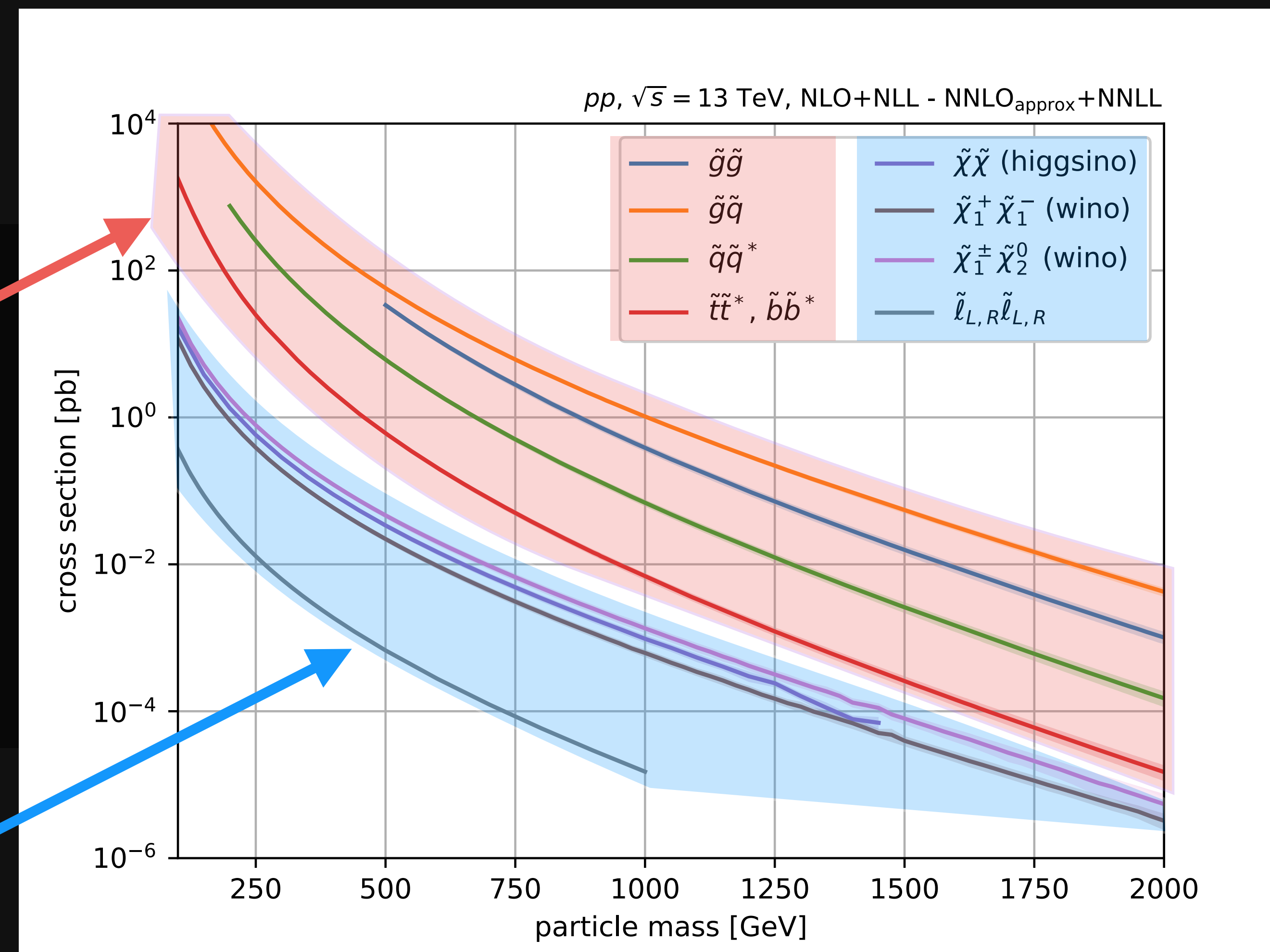


"SUSY is just around the corner."
— Carlos Wagner

The low-hanging fruit

- LHC at 13 TeV well-motivated to search for SUSY (*some searches were possible for the first time!*)
- **Strongly-produced**, with large color coupling, have highest cross-section in SUSY
- **Electroweak-produced** sparticles are subdominant

more often

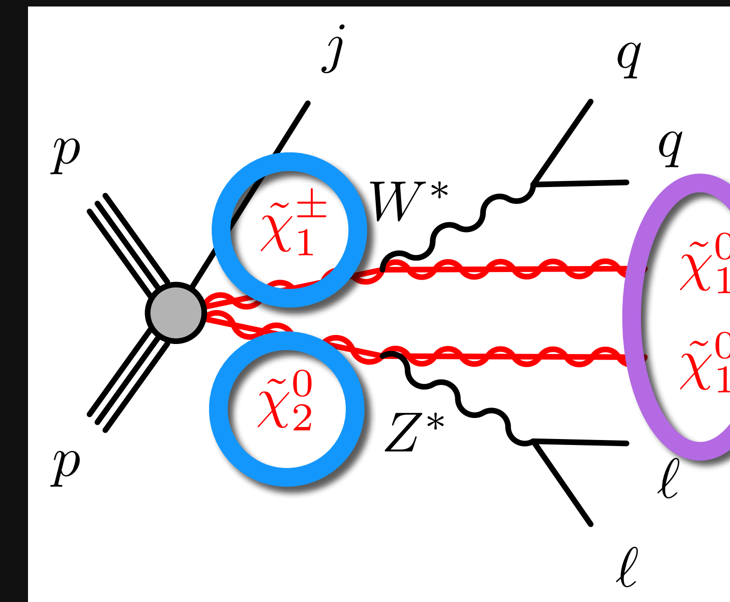


Search for strongly-produced sparticles!

(electroweak states may be first detected if high mass limits on strong production)

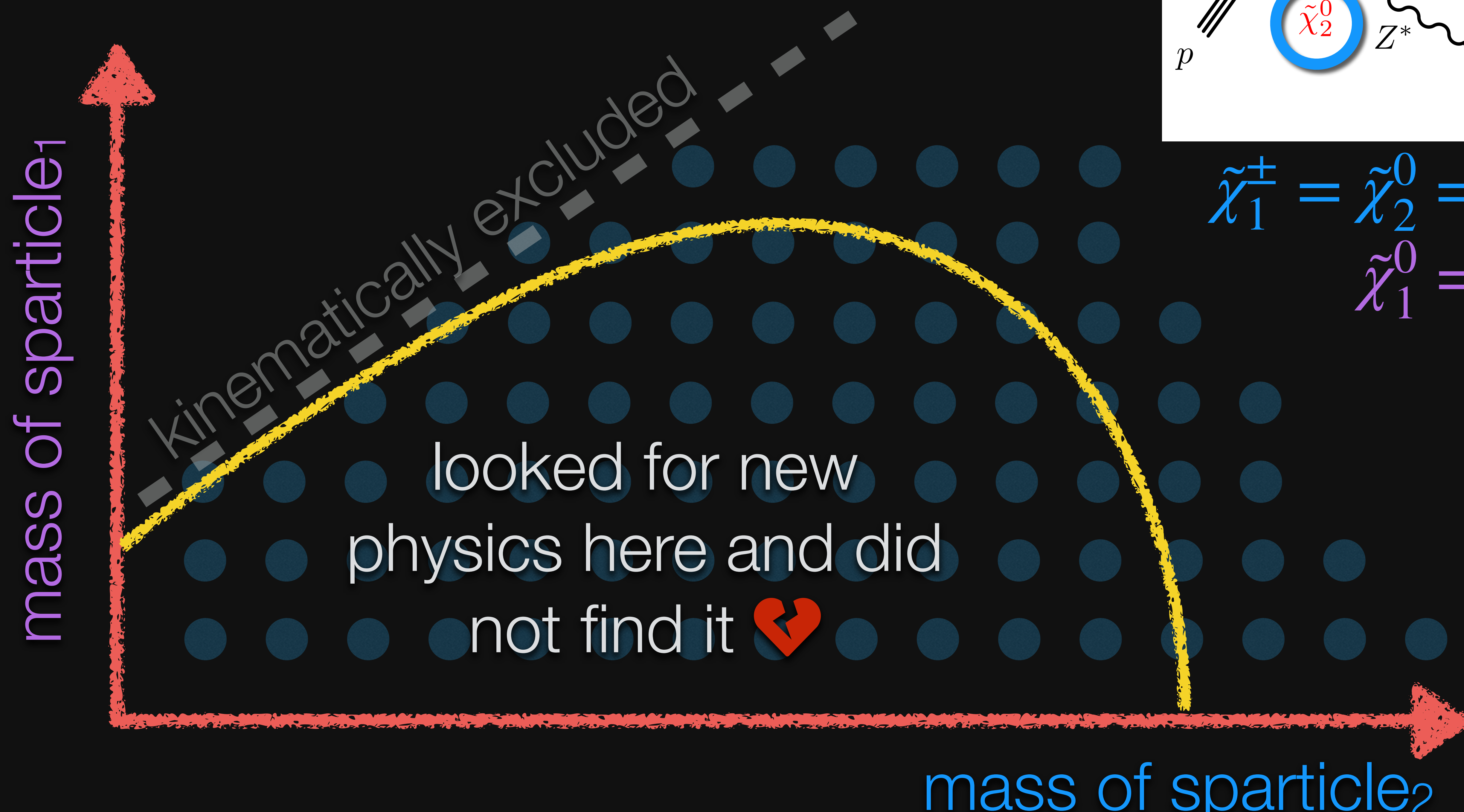
❗ *We can scan possible values of x, y in a 2-dimensional grid*

Hypothesis Testing



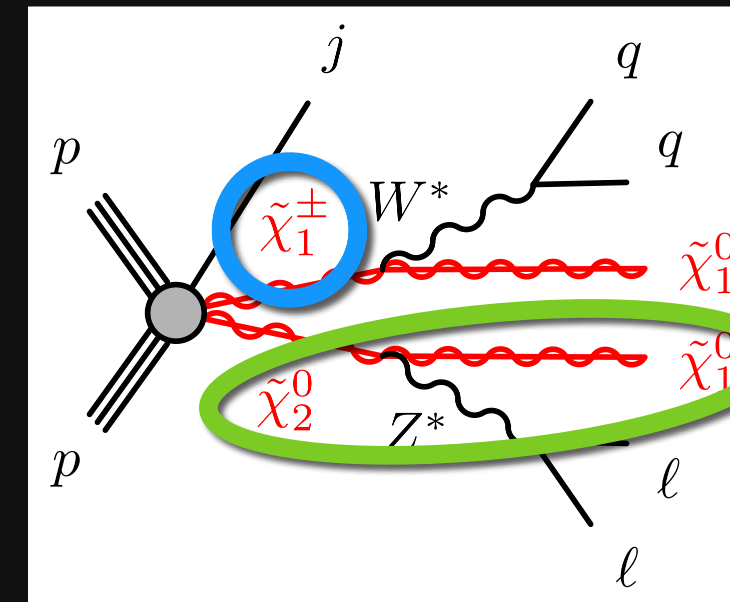
$$\tilde{\chi}_1^\pm = \tilde{\chi}_2^0 = x$$

$$\tilde{\chi}_1^0 = y$$



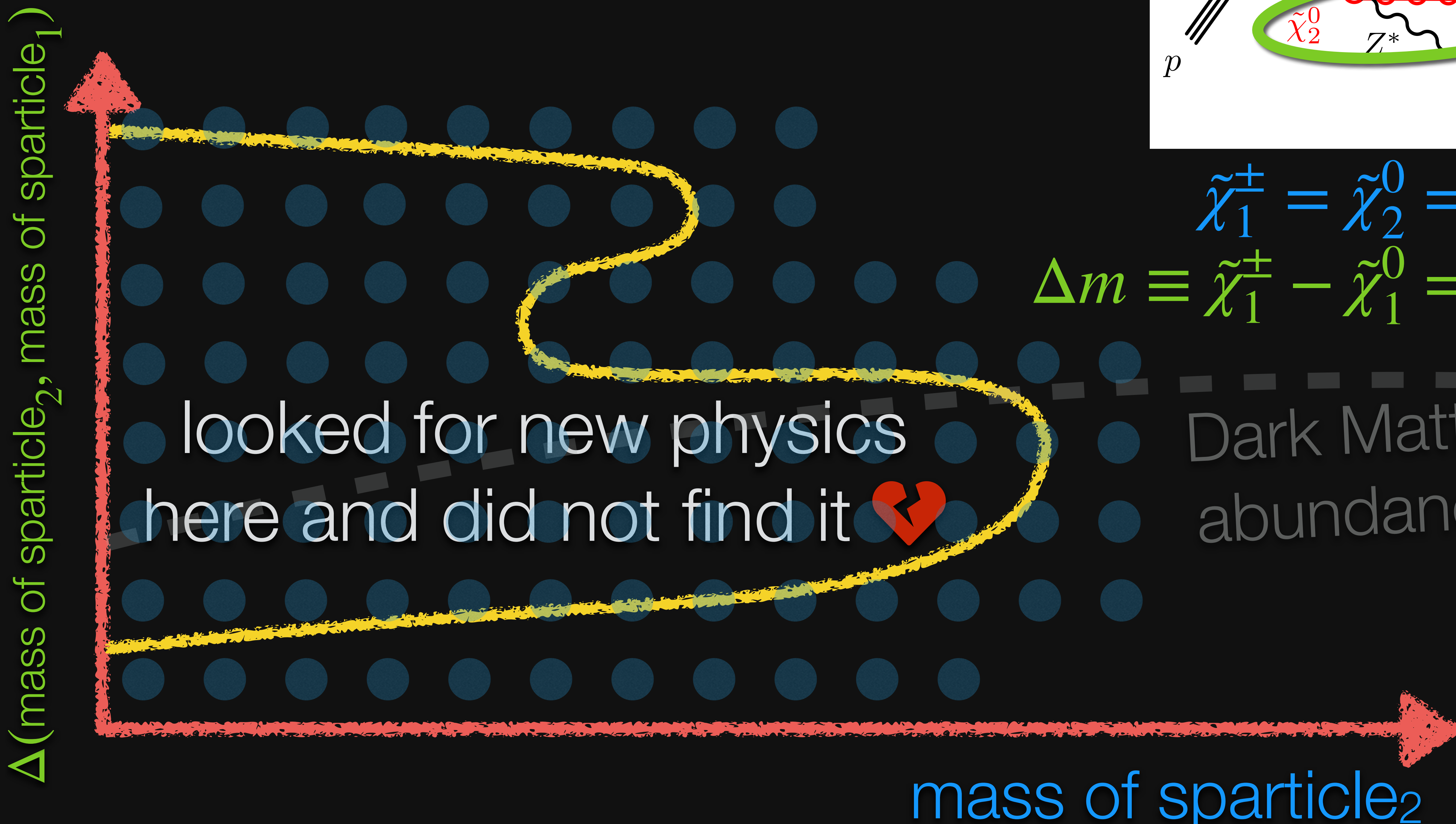
We can scan possible values of x, y in a 2-dimensional grid

Reframing as Δm



$\tilde{\chi}_1^{\pm} = \tilde{\chi}_2^{0} = x$

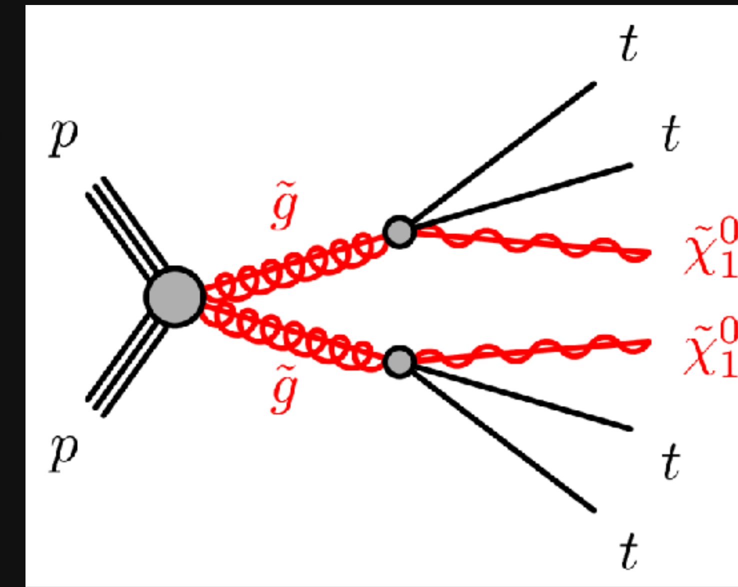
$\Delta m \equiv \tilde{\chi}_1^{\pm} - \tilde{\chi}_1^{0} = y$



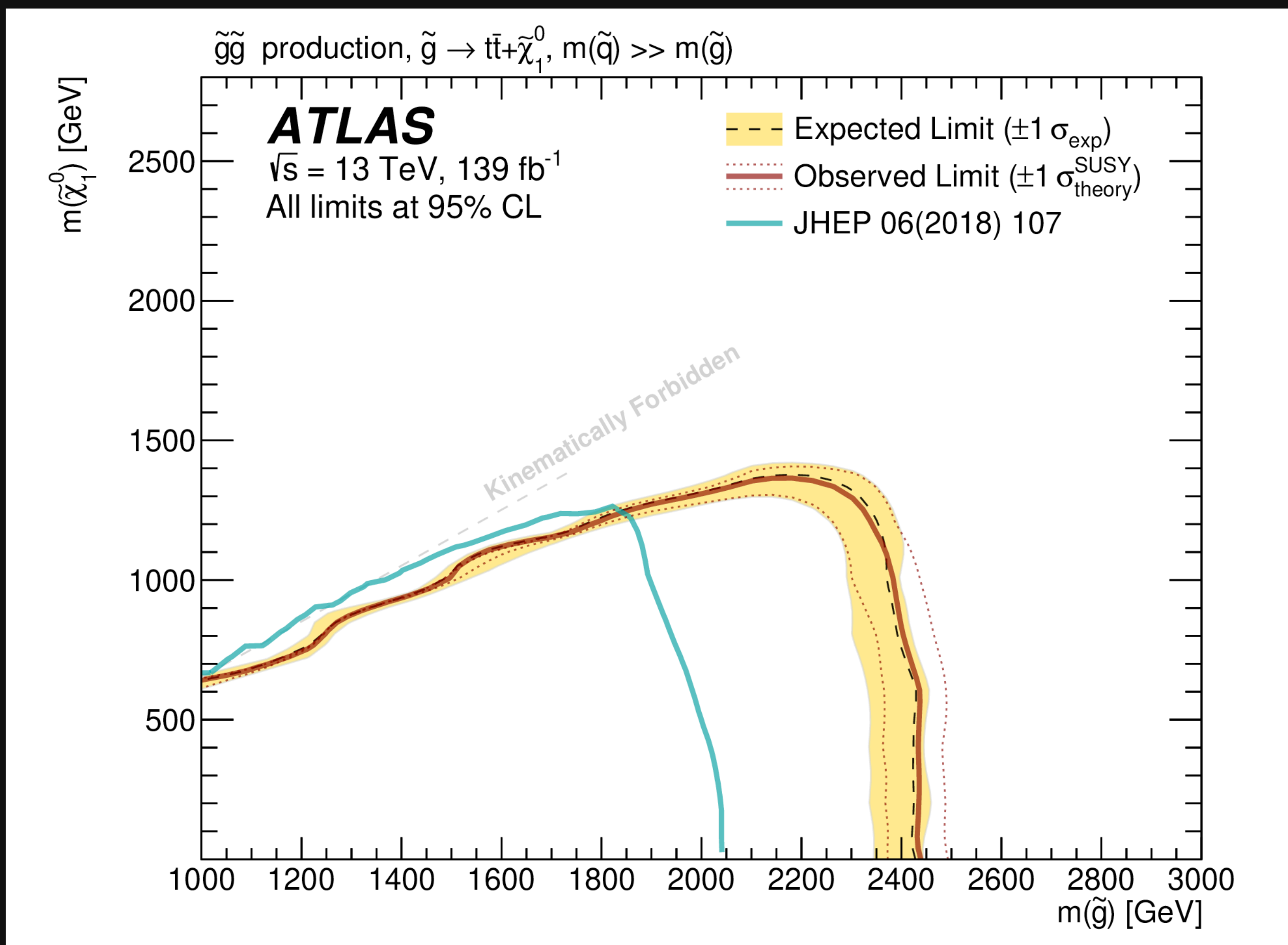
https://arxiv.org/abs/1605.09318
https://arxiv.org/abs/1711.01901
ATL-PHYS-PUB-2023-025

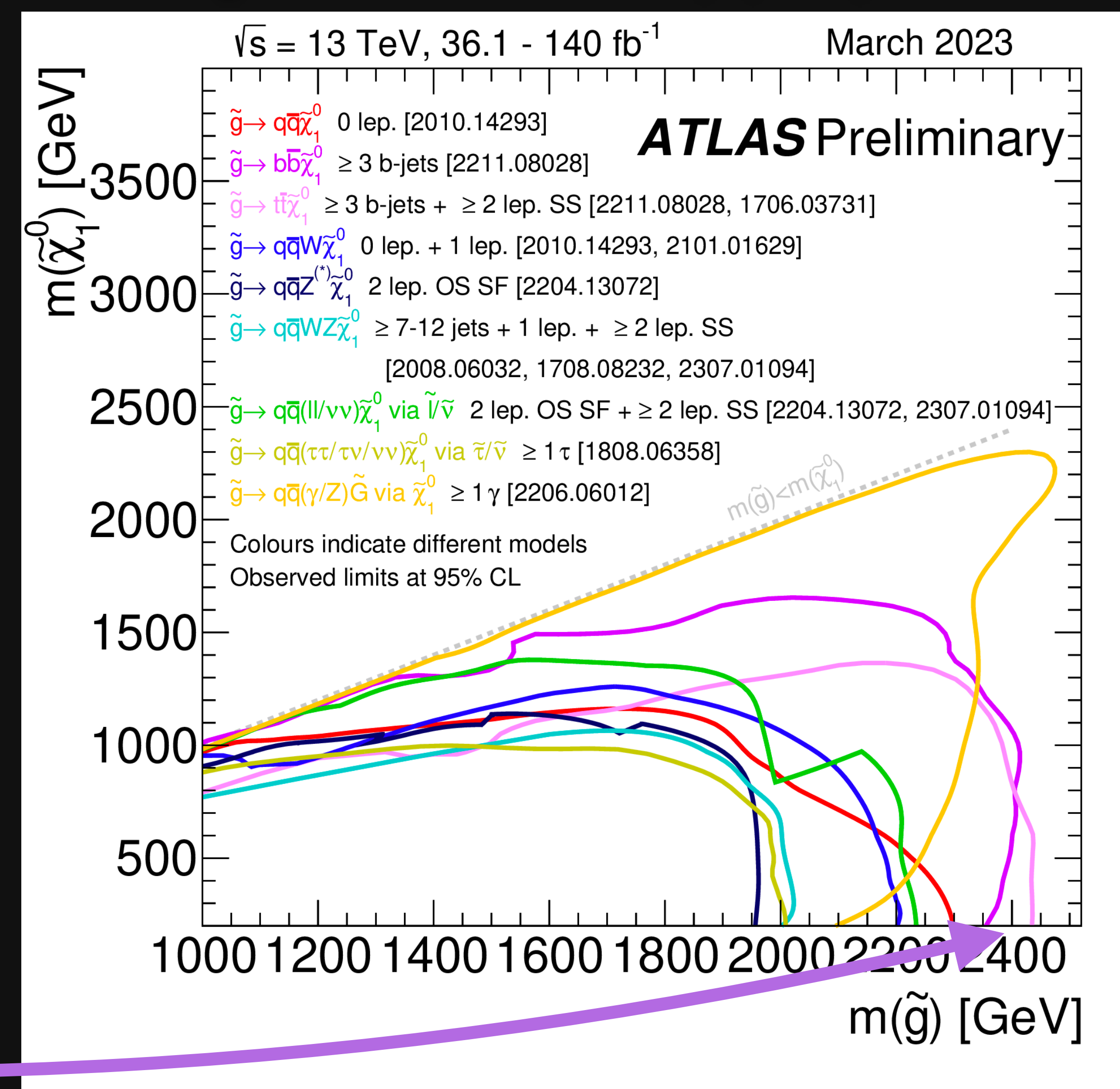
this is an analysis I've led for many years

Strong SUSY



gluino-mediated stop pair production





Strongest limit on gluino mass ~2.45 TeV @ 95% CL

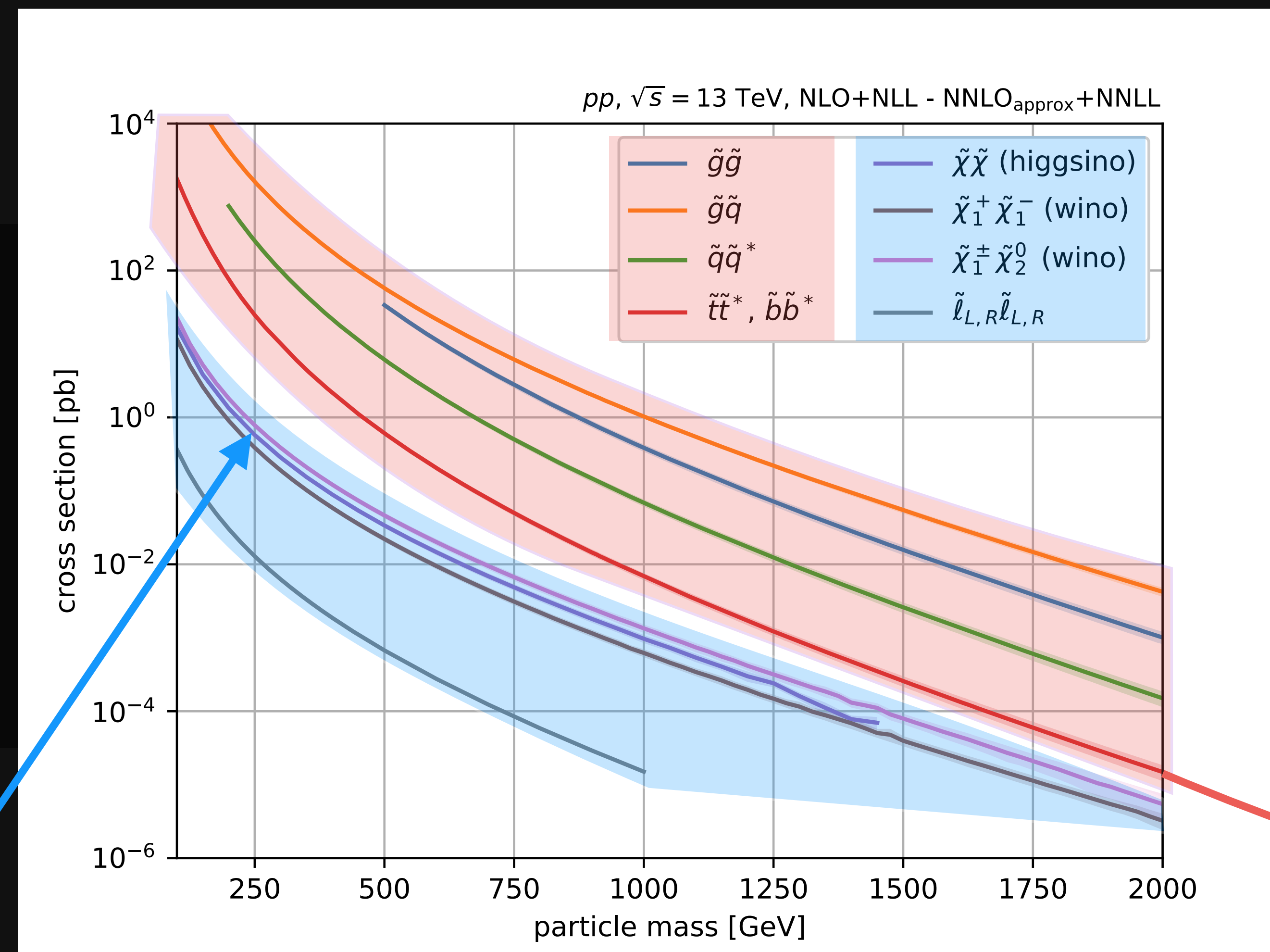
each contour represents different interpretations of a SUSY model

Search for strongly-produced sparticles!

Is SUSY ☠? Not quite…

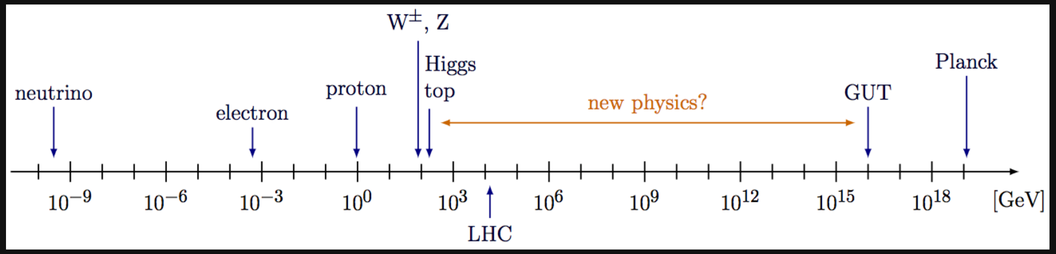
- Reaching the **energy limits** of our current machine searching for SUSY produced through strong interactions
- Bigger dataset → start hunting **rarer processes** to produce SUSY through electroweak interactions
  - *Can we also do more with what we have?* ***Yes!***

more often

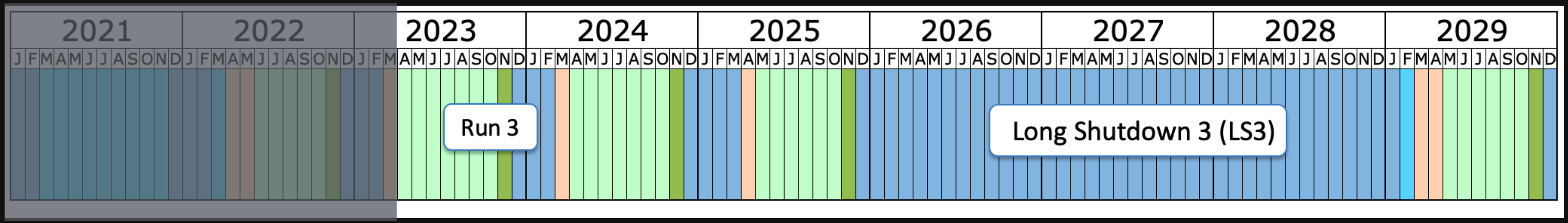


Not really "light" anymore! Maybe we should look **somewhere** else!

Questions so far



- ~~Strong SUSY isn't that well-motivated here, so perhaps SUSY is possibly electroweakly-produced?~~
  - 🔍 Keep searching using (incoming) Run 3+ data
- How do we make sure that our analysis results are still **interpretable** with new phenomenology today?
- How do we **combine** different analysis results to constrain the allowed SUSY models?



Statistical Techniques

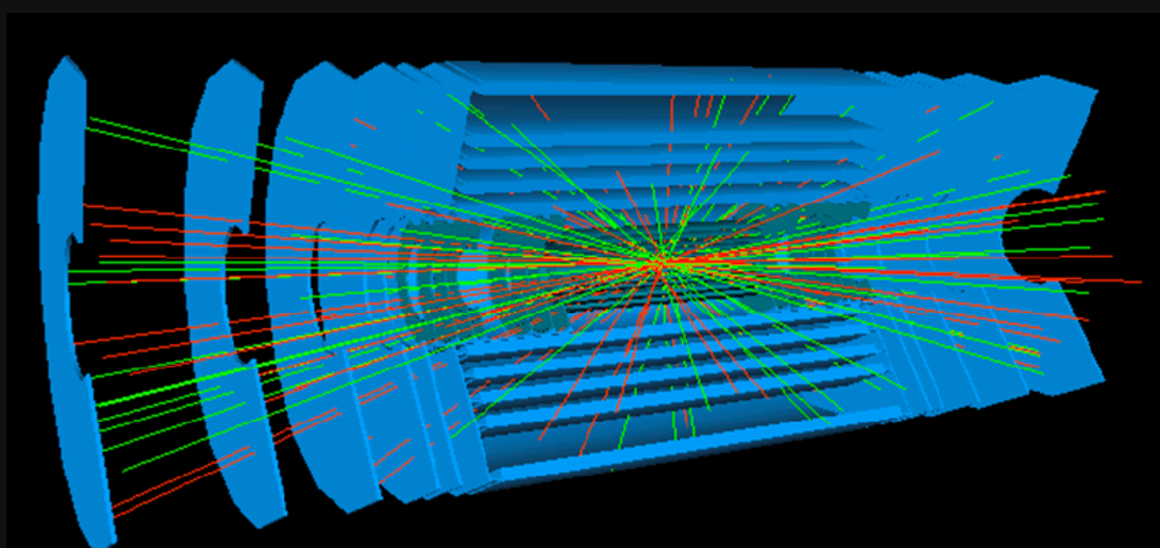
How do experimentalists count?

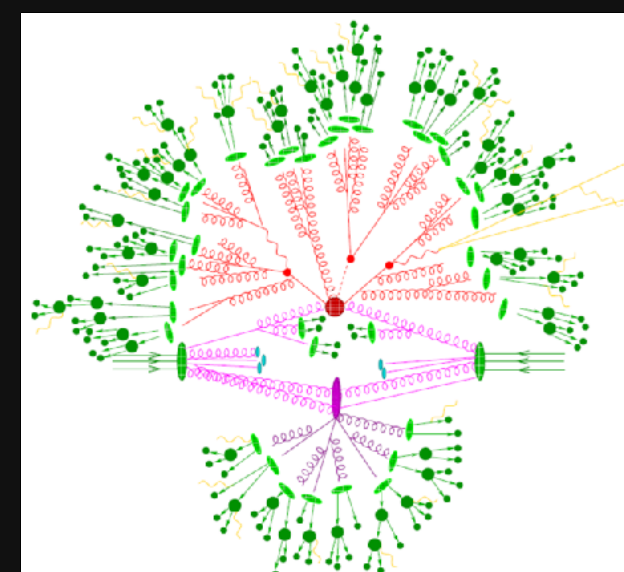
"Do you know why they call me the Count? Because I love to count! Ah-hah-hah!" — The Count (of Sesame Street)

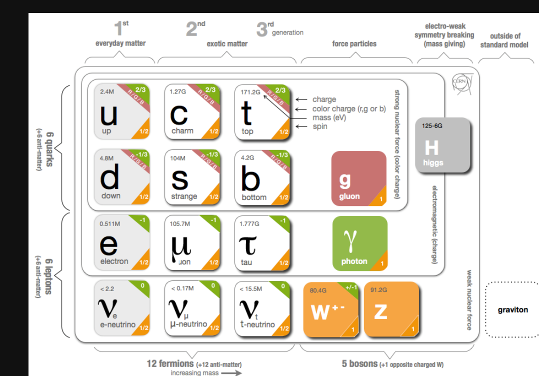
The Big Picture

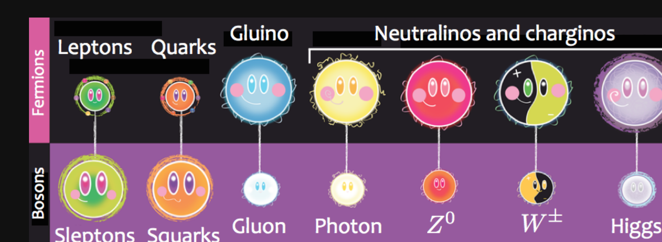
observations

model
(SM + SUSY)









$p(\text{data} = \text{observed})$

$p(\text{theory})$

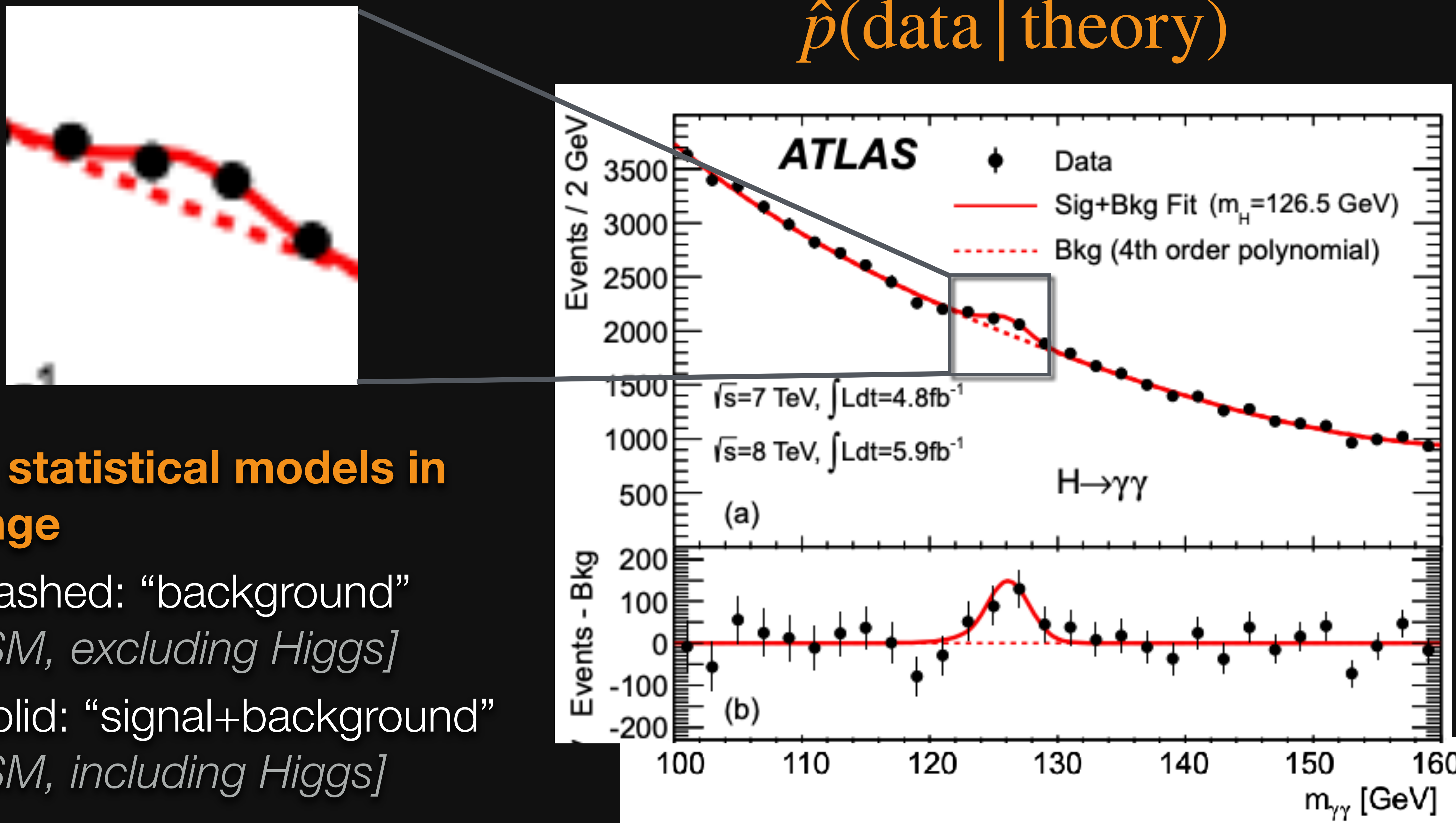
❗ **A likelihood function** encodes everything we know about the **detector**, the **theory**, and the **data**

[arXiv:1207.7214](#)
[Cowan (Statistical Data Analysis)](#)
[James (Statistical Methods in Experimental Physics)](#)

Statistical model ***inferences*** *can provide: p-values, confidence intervals, limits, expected yields, data/MC comparisons, etc…*

What is a statistical model?

$\hat{p}(\text{data} \,|\, \text{theory})$



- **Two statistical models in orange**
  - dashed: “background” *[SM, excluding Higgs]*
  - solid: “signal+background” *[SM, including Higgs]*

Hypothesis: is the Higgs boson part of the Standard Model?

https://indico.cern.ch/event/100458/

Back in 2000…

Origins I: The First "Statistics in HEP" conference

WORKSHOP ON CONFIDENCE LIMITS

CERN, Geneva, Switzerland
17–18 January 2000 CERN 2000–005

Massimo Corradi

Does everybody agree on this statement, to publish likelihoods?

Louis Lyons

Any disagreement? Carried unanimously. That's actually quite an achievement for this Workshop.

…[Fred James wants to be able to calculate coverage, Don Groom wants to able to calculate goodness of fit]…

Cousins

I thought the point of unanimity was that publishing the likelihood function was a *necessary* condition, not a sufficient condition.

But a practical problem remained: *How* to communicate multi-D likelihood?

⚠ ATLAS agreed to publish likelihoods!

THE MAIN DEVELOPERS

In 2019, we did it:


G. Stark


M. Feickert


L. Heinrich

pyhf ∂ifferentiable ℒikelihoods

New open release streamlines interactions with theoretical physicists

The ATLAS Collaboration has released the first open likelihoods from an LHC experiment.

12th December 2019 | By Katarina Anthony

Explore ATLAS open likelihoods on the HEPData platform. (Original image: Ahmet Anil Sen/Behance)

https://atlas.cern/updates/news/new-open-likelihoods

Courtesy of CERN

ATLAS releases 'full orchestra' of analysis instruments

01/14/21 | By Stephanie Melchor

The ATLAS collaboration has begun to publish likelihood functions, information that will allow researchers to better understand and use their experiment's data in future analyses.

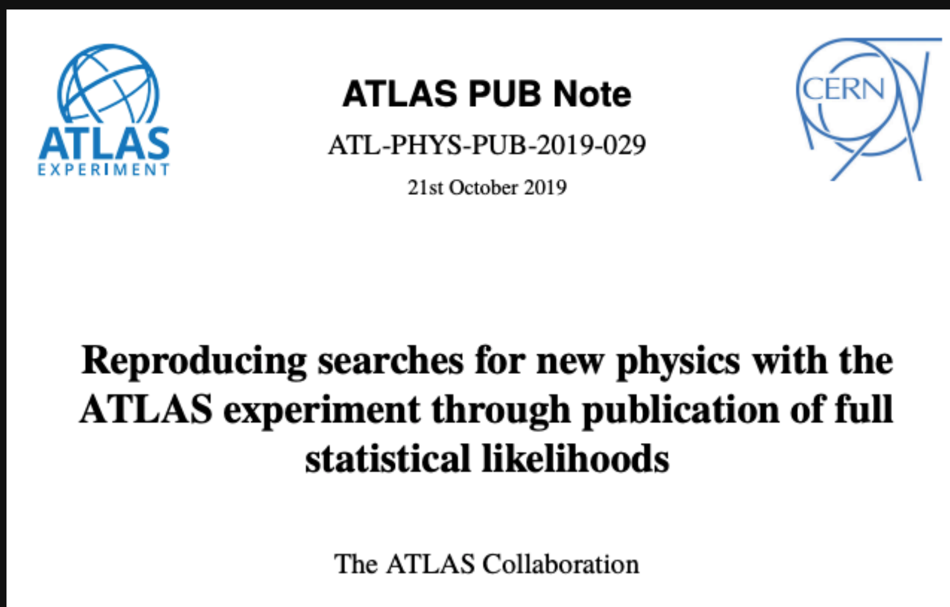
Meyrin, Switzerland, sits serenely near the Swiss-French border, surrounded by green fields and the beautiful Rhône river. But a hundred

https://www.symmetrymagazine.org/article/atlas-releases-full-orchestra-of-analysis-instruments

ATLAS-CONF-2019-011 JHEP12(2019)060 ATL-PHYS-PUB-2019-029
https://www.hepdata.net/record/ins1748602

Computationally efficient!

launch binder


ATLAS PUB Note

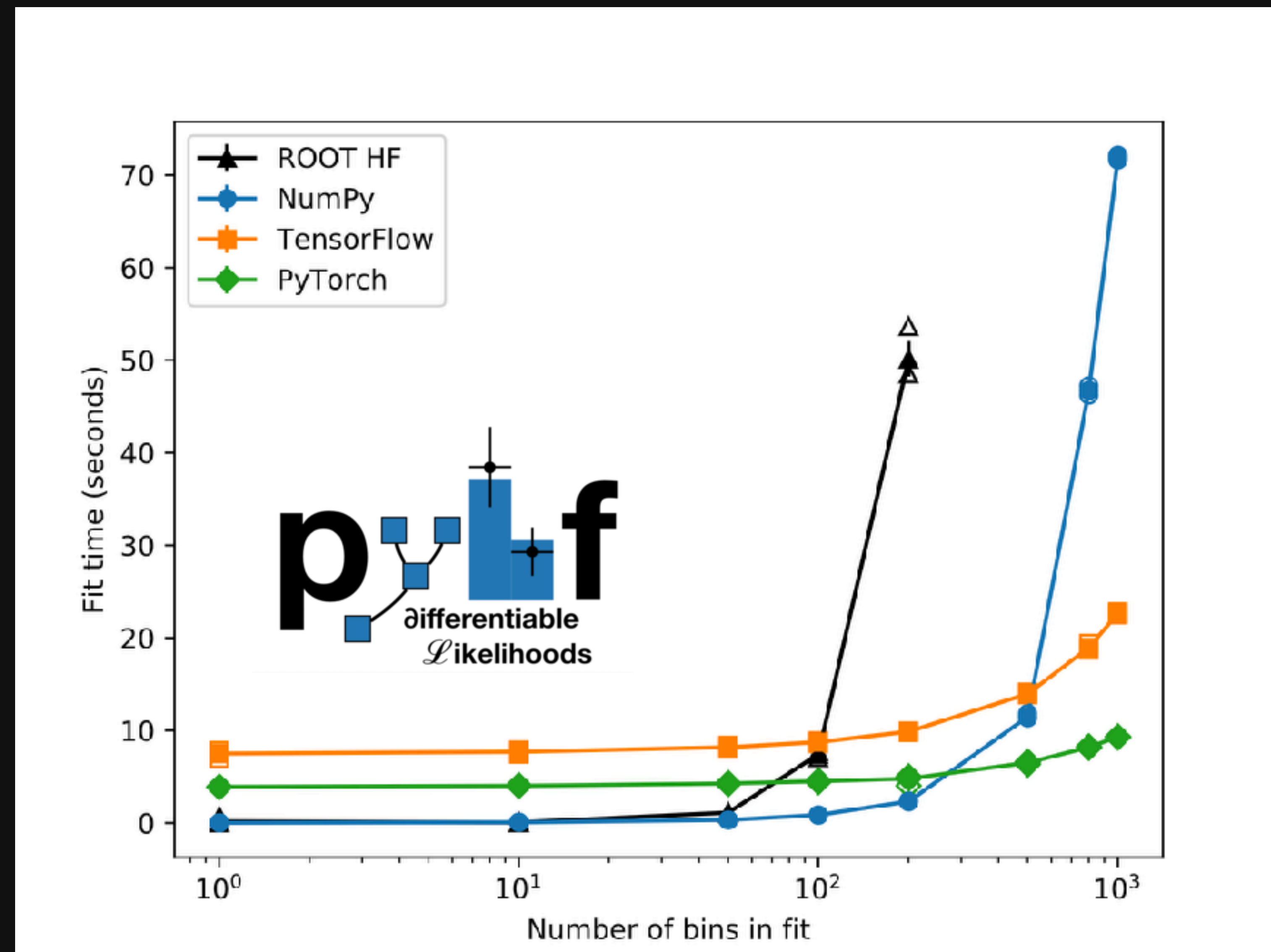
ATL-PHYS-PUB-2019-029

21st October 2019

Reproducing searches for new physics with the ATLAS experiment through publication of full statistical likelihoods

The ATLAS Collaboration

PyTorch TensorFlow NumPy



“python -m pip install pyhf”

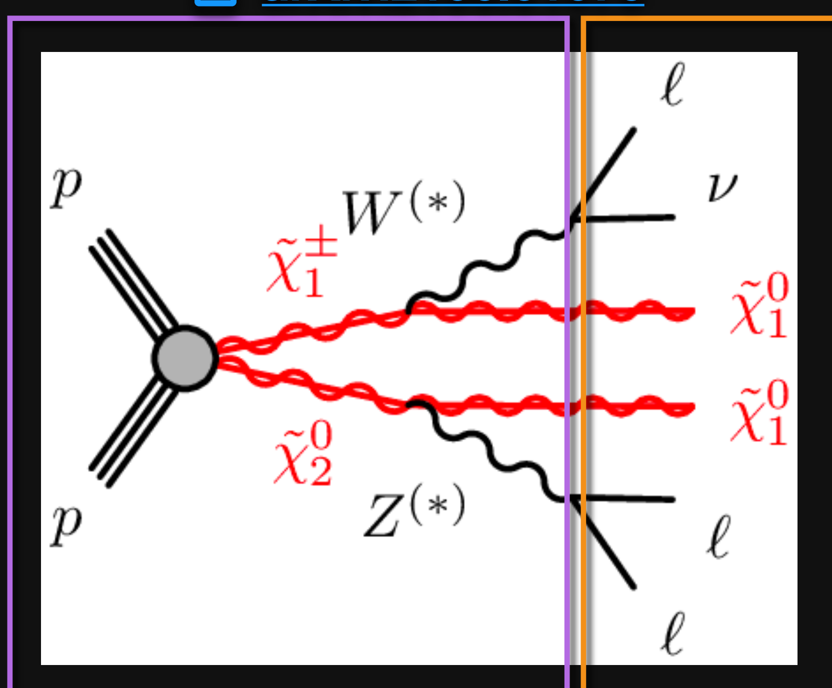
orders-of-magnitude faster inference

arXiv:1911.12606 ATLAS-CONF-2020-015 arXiv:2106.01676 ATL-PHYS-PUB-2021-019
atlas.cern/updates/briefing/new-higgsino-limits

E.G.: Stat. Combination (I)

- Multiple analyses with different **signatures** can still target the same **model**

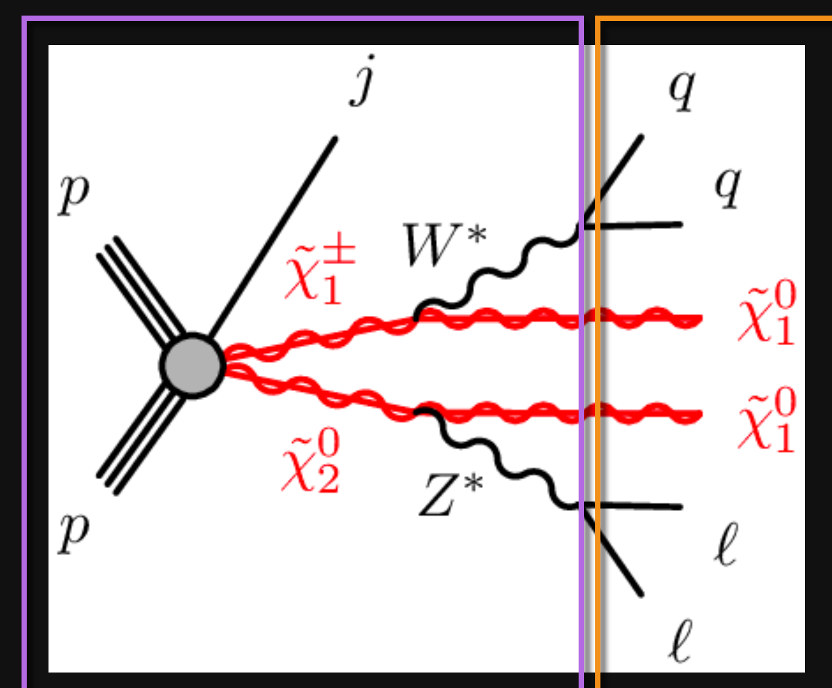
ATLAS-CONF-2020-015
arXiv:2106.01676



signature: $3\ell + 0j +$ E_T^{miss}

“3-lepton”

arXiv:1911.12606



signature: $2\ell + 3j +$ E_T^{miss}

“soft 2-lepton”

arXiv:1911.12606 ATLAS-CONF-2020-015 arXiv:2106.01676 ATL-PHYS-PUB-2021-019
atlas.cern/updates/briefing/new-higgsino-limits

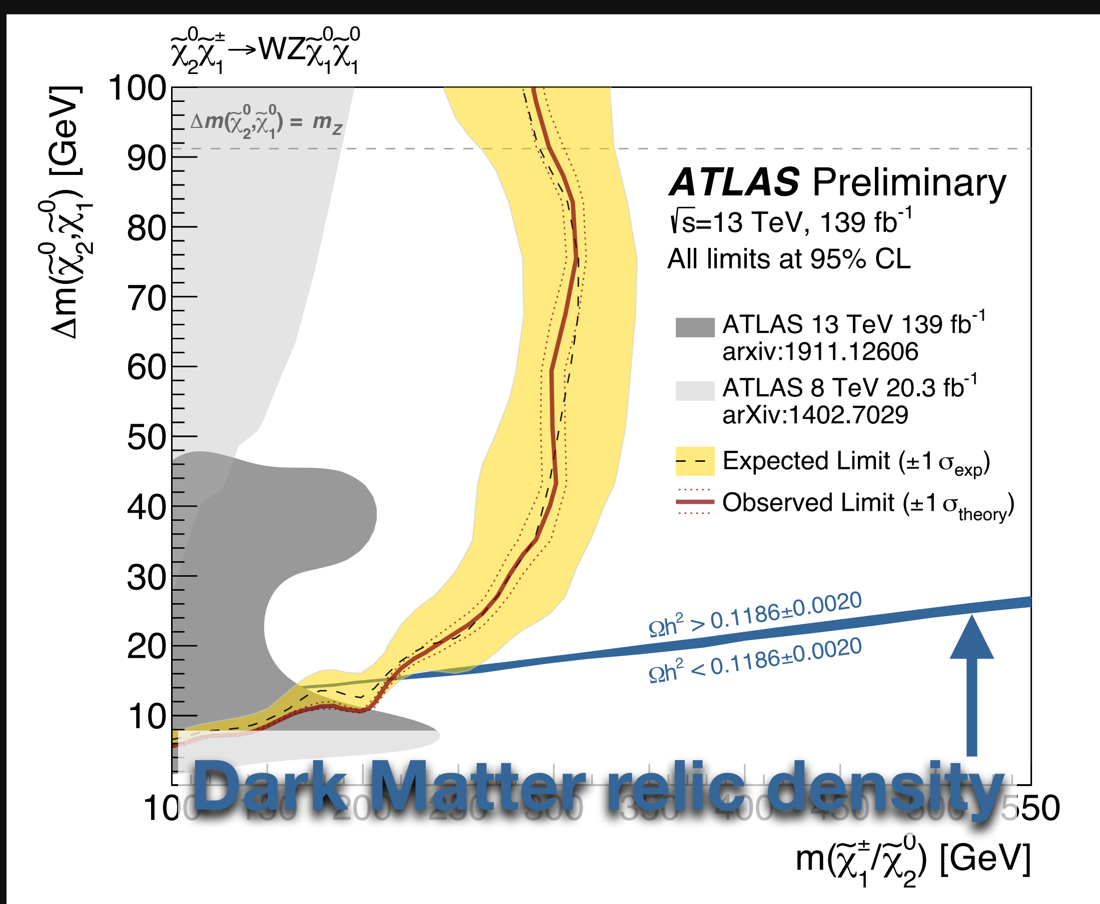
E.G.: Stat. Combination (II)

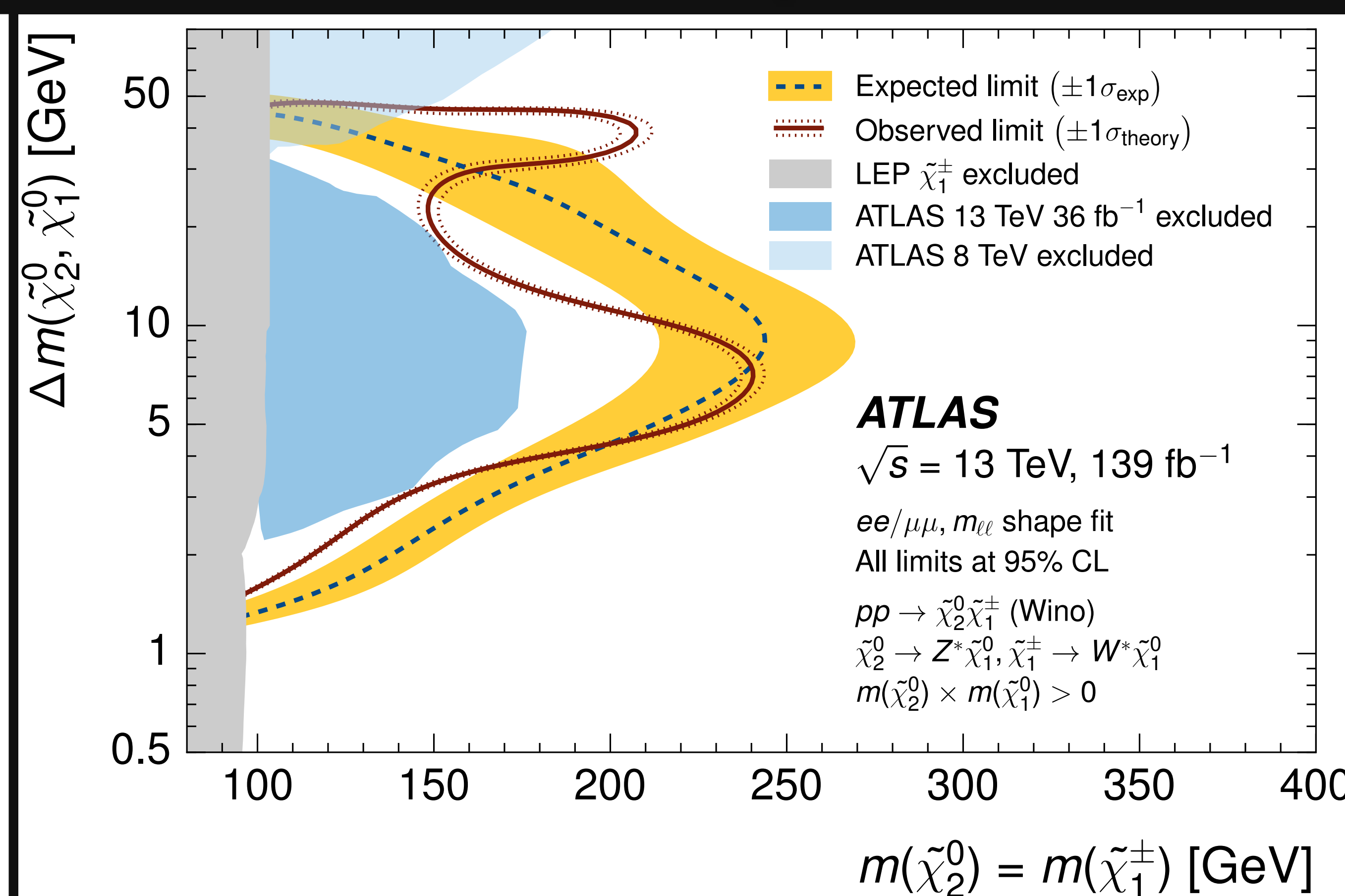
- Goal: **combine multiple searches** to paint a tapestry of our sensitivity to a set of simplified models (**electroweak-production**) which decay to on-shell/off-shell Standard Model bosons (W/Z)

three lepton

soft two lepton

$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$

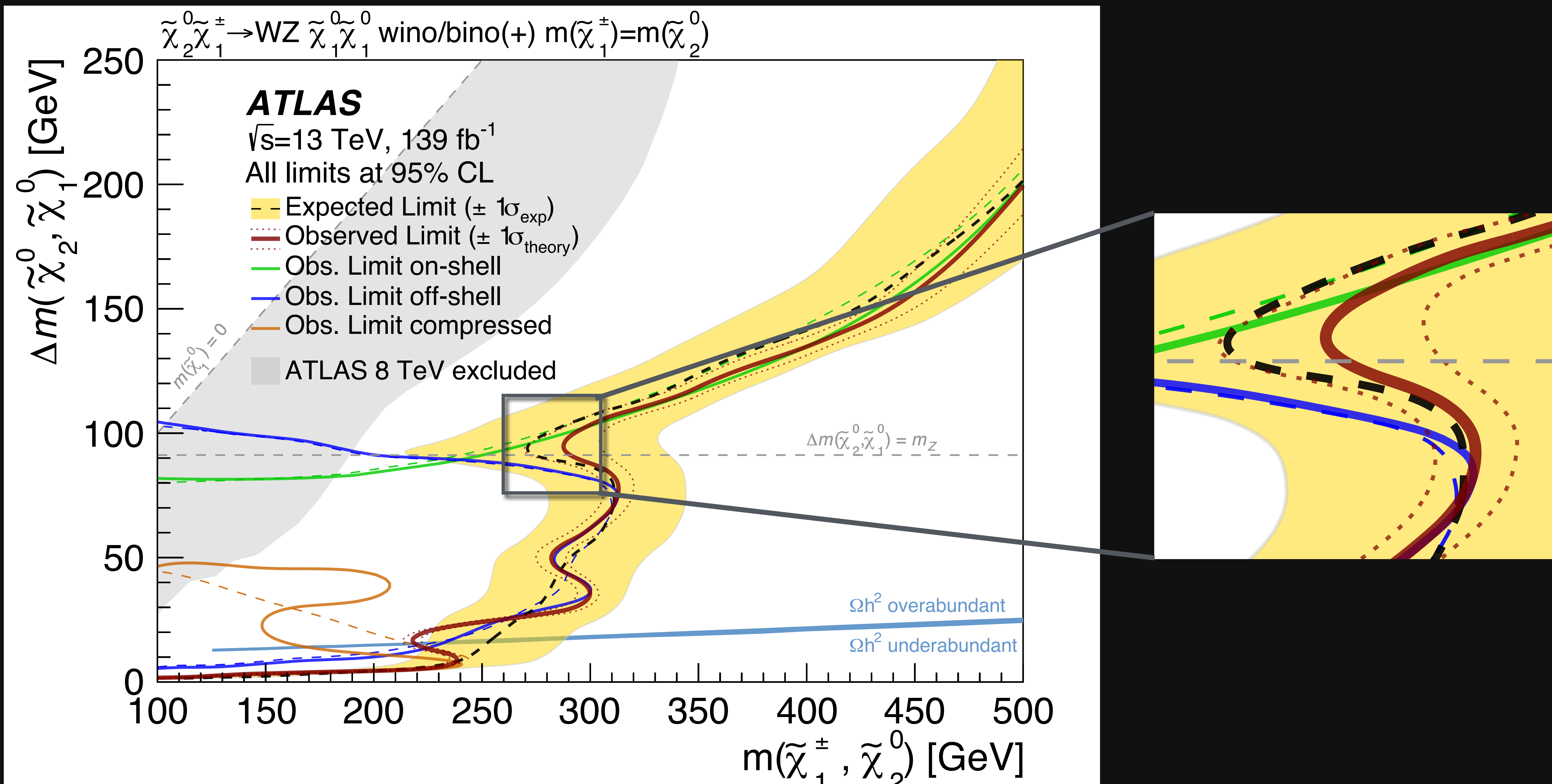




$m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0)$ $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0)$

arXiv:1911.12606 ATLAS-CONF-2020-015 arXiv:2106.01676 ATL-PHYS-PUB-2021-019
atlas.cern/updates/briefing/new-higgsino-limits

E.G.: Stat. Combination (III)



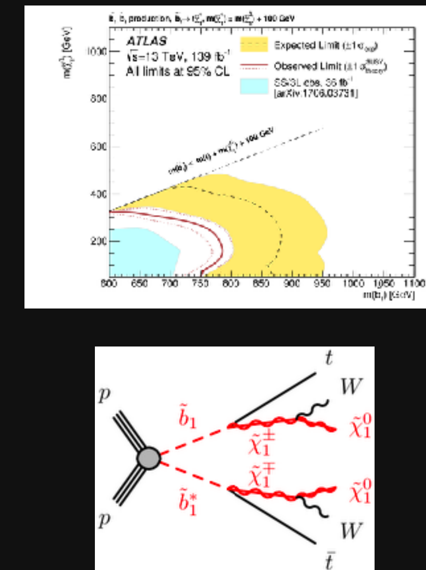
Not possible without my work externally on pyhf and reproducibility, but also driving it internally in the ATLAS collaboration

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

More public models!

(since 2021!)

SUSY-2018-09



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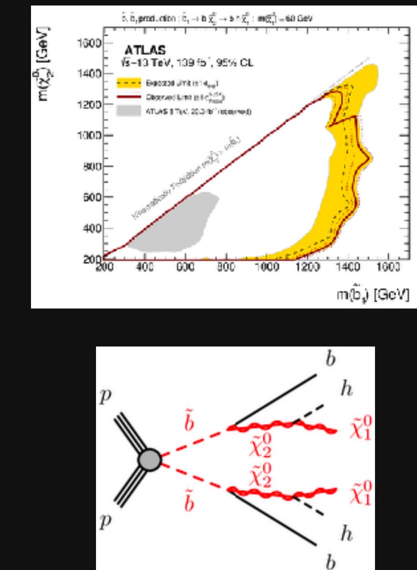

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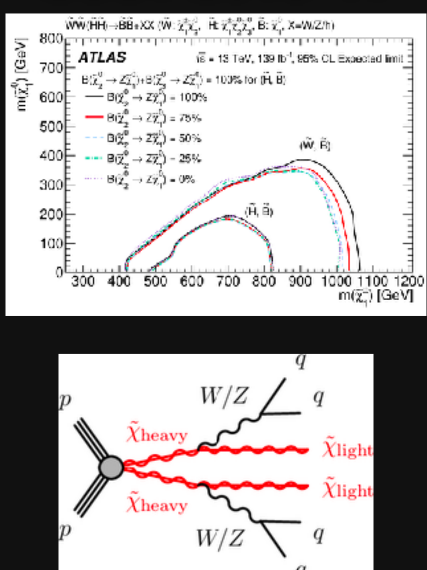
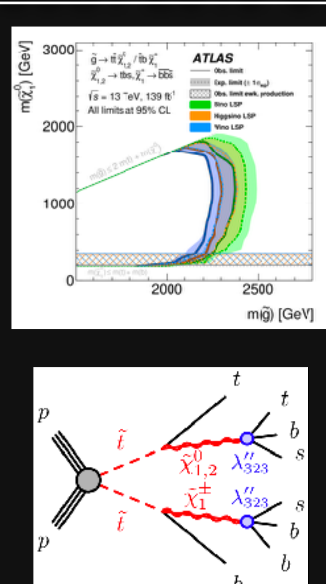


SUSY-2019-04



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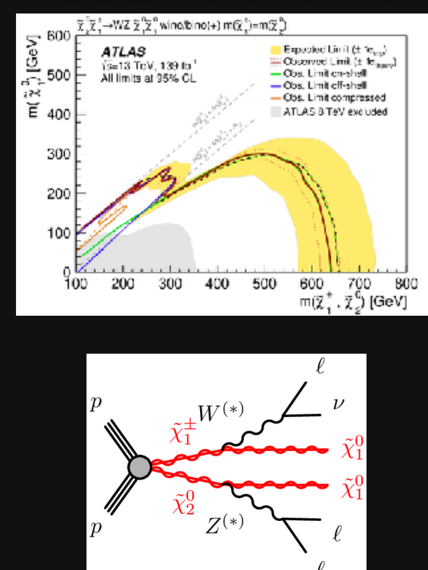

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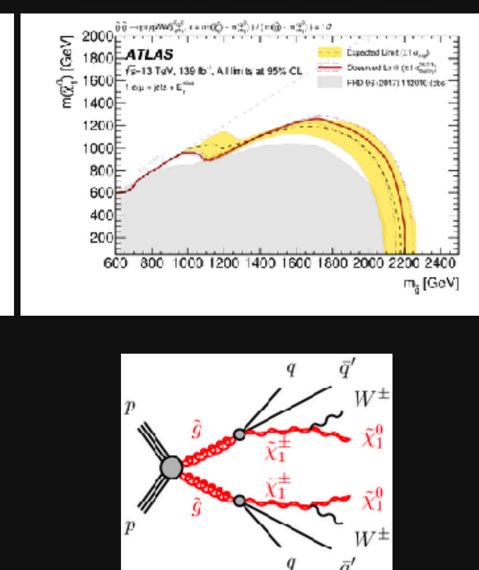
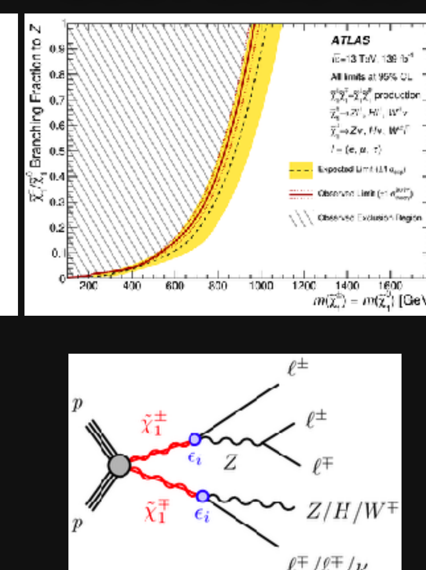


SUSY-2018-36



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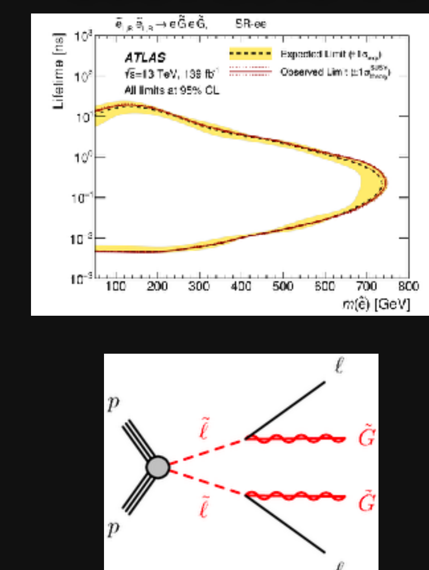

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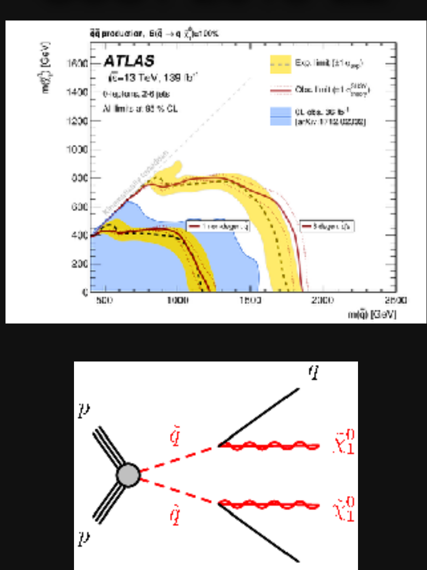

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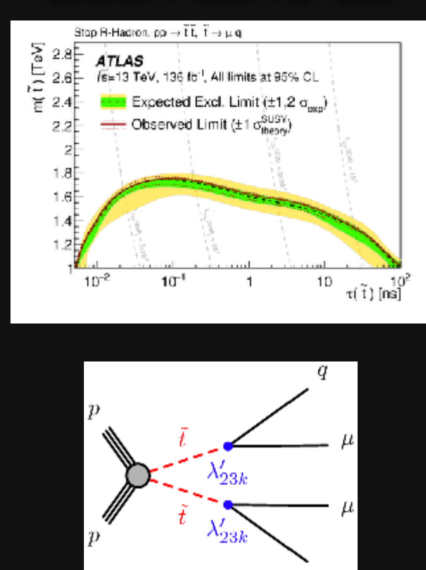
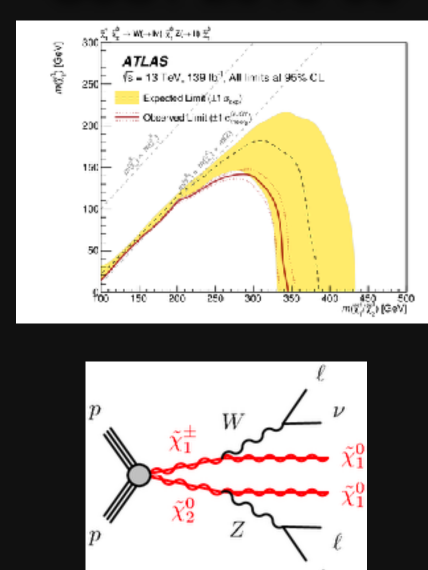
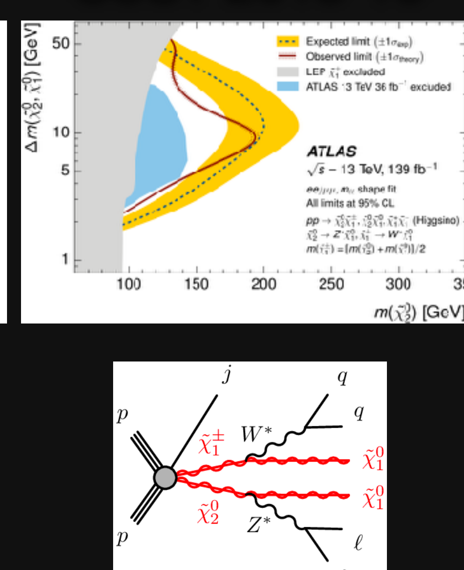


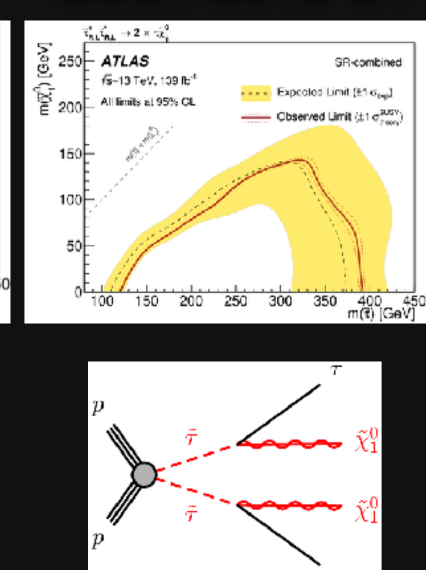
SUSY-2018-06



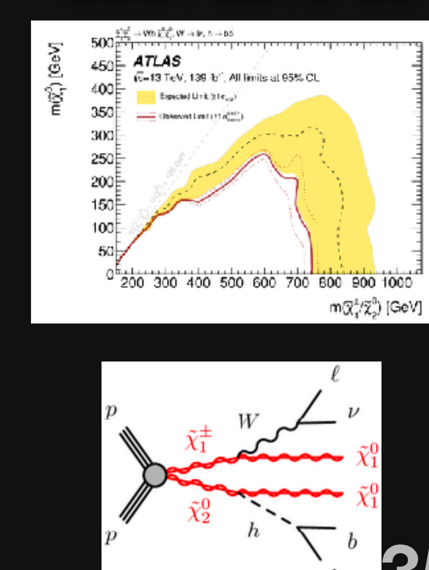
SUSY-2018-16



SUSY-2018-04



SUSY-2019-08



❗ **Builds on top of my work with pyhf**

Integration into theory tools

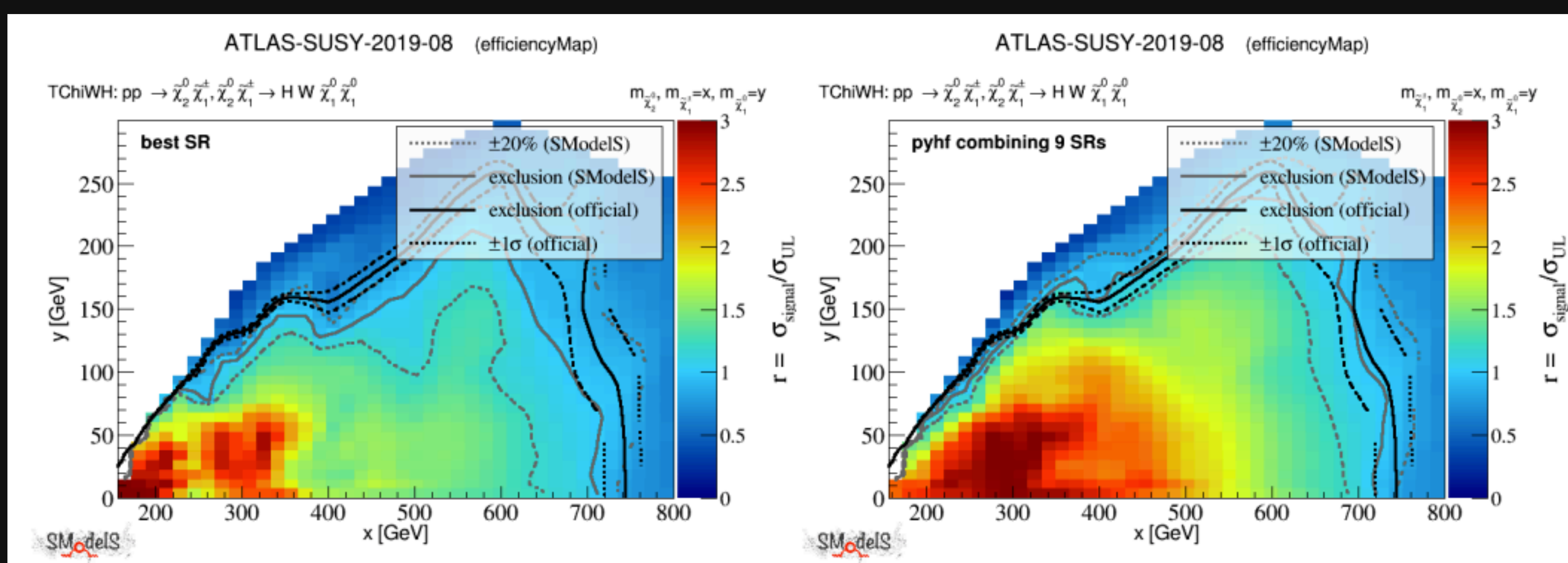
"if you build it, they will come"

arXiv:2009.01809

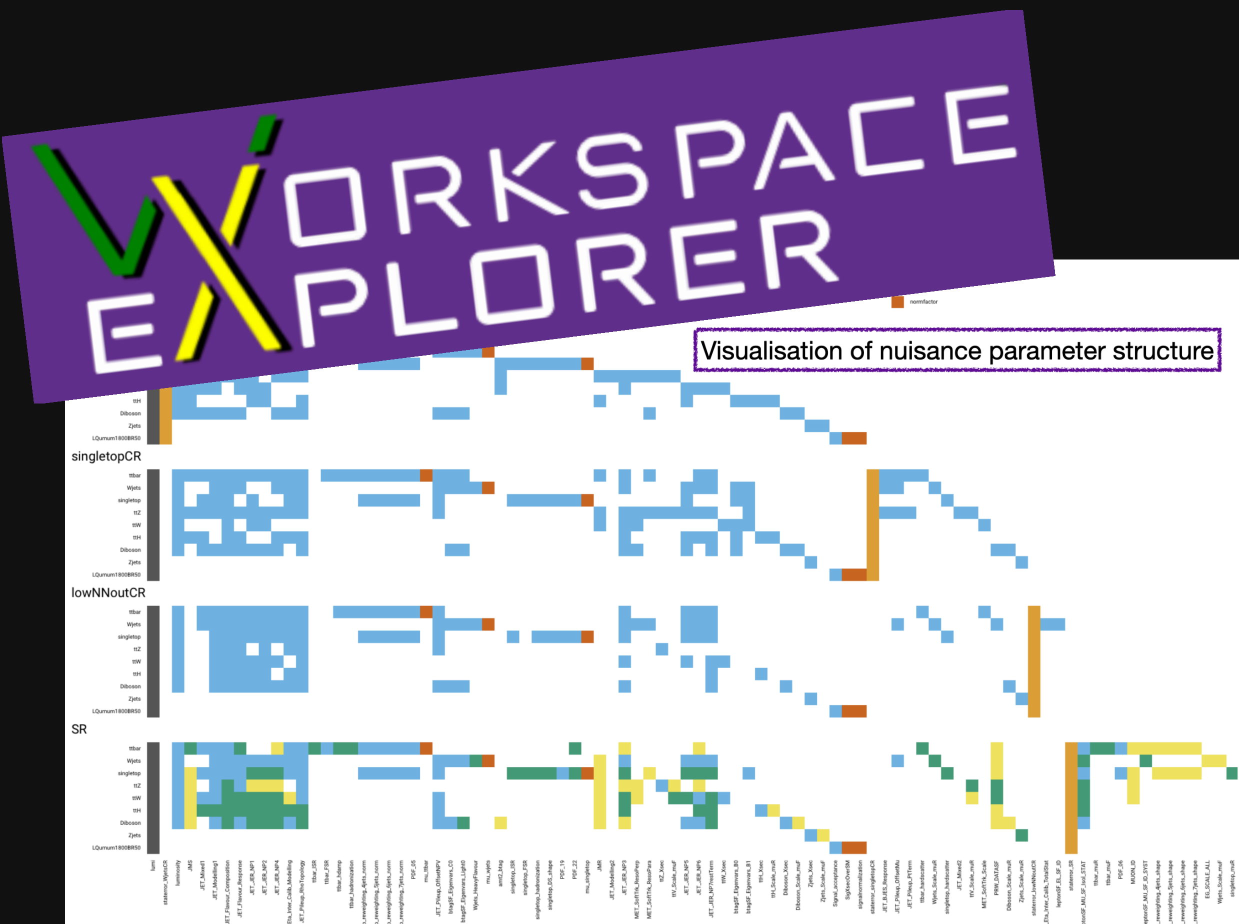
A SModelS interface for pyhf likelihoods

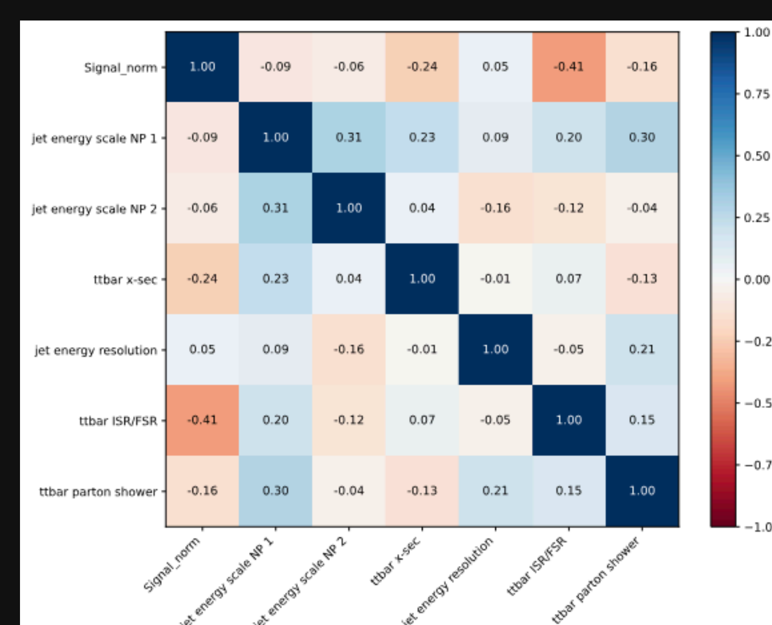
Gaël Alguero[a], Sabine Kraml[a], Wolfgang Waltenberger[b,c]

[a] *Laboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, 53 Avenue des Martyrs, F-38026 Grenoble, France*
[b] *Institut für Hochenergiephysik, Österreichische Akademie der Wissenschaften, Nikolsdorfer Gasse 18, 1050 Wien, Austria*
[c] *University of Vienna, Faculty of Physics, Boltzmanngasse 5, A-1090 Wien, Austria*



... and other tools





https://scikit-hep.org/pyhf/citations.html

…and other experiments

LHC QCD: arXiv:2012.09120

How to discover QCD Instantons at the LHC[1]

Simone Amoroso[a] Deepak Kar[b] Matthias Schott[2c]

[a]DESY, Hemburg, Germany
[b]University of Witwatersrand, South Africa
[c]Johannes Gutenberg-University, Mainz, Germany

E-mail: matthias.schott@cern.ch

Sensitivity of Future Hadron Colliders to Leptoquark Pair Production in the Di-Muon Di-Jets Channel

B. C. Allanach[1], Tyler Corbett[2], Maeve Madigan[a,1]

[1]DAMTP, University of Cambridge, Wilberforce Road, Cambridge, CB3 0WA, United Kingdom
[2]The Niels Bohr International Academy, Blegdamsvej 17, University of Copenhagen, DK-2100 Copenhagen, Denmark

FCC: arXiv:1911.04455

EIC: arXiv:2102.06176

Charged Lepton Flavor Violation at the EIC

Vincenzo Cirigliano, Kaori Fuyuto, Christopher Lee, Emanuele Mereghetti, and Bin Yan

Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.
E-mail: cirigliano@lanl.gov, kfuyuto@lanl.gov, clee@lanl.gov, emereghetti@lanl.gov, binyan@lanl.gov

Search for new phenomena in events with two opposite-charge leptons, jets and missing transverse momentum in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

ATLAS: arXiv:2102.01444

SEARCH FOR $B^+ \to K^+ \nu\bar{\nu}$ DECAYS WITH AN INCLUSIVE TAGGING METHOD AT THE BELLE II EXPERIMENT

On the single leptoquark solutions to the B-physics anomalies

Andrei Angelescu,[1,*] Damir Bečirević,[2,†] Darius A. Faroughy,[3,‡] Florentin Jaffredo,[2,§] and Olcyr Sumensari[2,¶]

Belle II: arXiv:2103.12504, arXiv:2105.05754

Searching for dark tridents with the MicroBooNE detector - 05/04/2023

µBooNE

Expected li

- Final BDT/CNN distributions are passed to *Pyhf* (

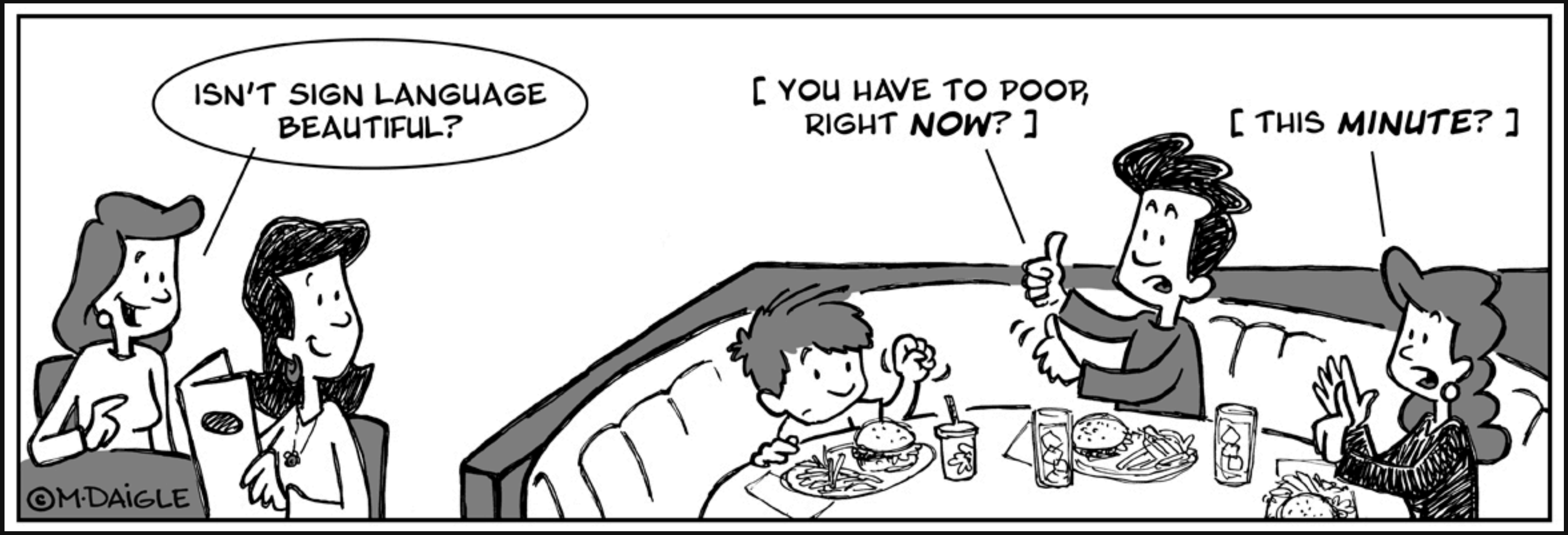
µBooNE: indico:e1261135

Hunting wino and higgsino dark matter at the muon collider with disappearing tracks

Rodolfo Capdevilla,[a,b] Federico Meloni,[c] Rosa Simoniello,[d] Jose Zurita[e]

µ-collider: arXiv:2102.11292

Theory/experiment adoption across the field



Outreach

Making physics more:

approachable and accessible

"Places such as CERN become ever more important: places where people from around the world come together to show what can be achieved when people overcome their differences to work towards common goals that ultimately bring benefit to all of humanity.." — Fabiola Gianotti

Sign Language

70+ million people in the world **use sign language**

- Different from **country to country**
  - ASL, LSF, DGS, LIS, NZSL, Auslan, BSL, etc…
- Different **Grammar**
  - English (Subject-Object-Verb) vs ASL (Time-Subject-Verb-Object)
  - EXAMPLE: "The boy threw the ball." vs "BALL, BOY THROW" / "BOY THROW BALL"
  - TOPICALIZATION: "She gave me money." vs "MONEY? she-GIVE-me"
- Each sign is composed of **five parameters**. Altering one parameter changes the entire meaning
  - Handshape (HS), Palm Orientation (PO), Location, Movement, and Facial Expressions (NMS)
  - EXAMPLE: cool/apple/Bronx/ask/need/must/manage/scar/etc…

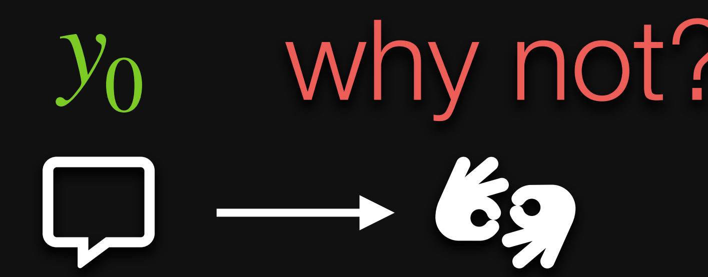
Phonology and Parameters

- Elementary particles are the **building blocks of matter**.
- The five parameters are the **building blocks of signs**.

- **Matter** is made up of **elementary particles**
  - **proton**: up, up, down
  - **neutron**: up, down, down

- **Signs** are built up using **parameters**
  - **mother**: HS5, PO-left, chin
  - **father**: HS5, PO-left, forehead

Access Difficulties



- Interpreters don't often have a PhD (or any degree) in STEM!
  - Interpretation of meaning (ASL) vs transliteration of what is said (PSE)
  - PSE **relies heavily on Deaf client** to fill in the information
- Direction of interpretation: *signs correlate to meaning, not with English words*
  - Interpreters not familiar with content may not be able to voice Deaf client accurately
    - Deaf client switches from ASL to PSE to ensure communication; or
    - Deaf client voices themselves, **heavy load on the interpreter**

- Lack of signed vocabularies, rely heavily on contextual information
  - **Heavy cognitive load on both** the interpreter and Deaf client
  - **Example**: No sign for dark matter, so sign #DM to refer to "that word that looks like D— M—"

! Lack of concepts (for Deaf) and lack of vocabulary (for interpreters)

https://aslcore.org/

ASLCore

- Focus on developing concepts/signs for first-year core college courses
- Alternatives to ASLCore exist such as
  - ASLClear (K-12 education focus) [https://clear.aslstem.com/app/#/]
  - STEM forum (no focus, user-contributed) [https://aslstem.cs.washington.edu/]
- Teams are composed of:
  - Deaf content expert(s): knows the concepts of the content
    - **(I'm the only Deaf Physicist with a PhD in the U.S. that I know of)**
  - Deaf language masters: knows the linguistics, language, and translation
  - interpreter consultants: brings experience of interpreting these concepts in classrooms

https://aslcore.org/

Examples

WELCOME TO **ASLCORE!**

- **PARTICLES**: Closed small C, champagne flick multiple
- **STANDARD MODEL**: NDH O PO side, DH 4 GRID-TABLE
- **RADIATE/RADIATION**: 2H A HS TOGETHER to 5 wiggle outwards
- **ENERGY**: bent-L, shake
- **LUMINOSITY**: NDH B PO up, DH AND HS open-twist to 5 HS (make sure DH palm always touch)
- **COLLISION** (Quantum Physics): Moving FLAT O to Open-Hand 5 twist (make sure back of hands are touching at the end of the sign)

https://aslcore.org/

Expansion Example

- What are atoms? Atoms are atomic particles that have many properties and are composed of three different subatomic particles: electrons, protons, and neutrons. The electrons form the atom’s “cloudy” atmosphere. At the center of an atom is the nucleus where all the protons and neutrons live. Are protons and neutrons elementary particles? Nope, they can be broke up into even smaller particles. For example, the proton is made of three quarks: up, up, down.

Key features: “cinematic ASL”

Outreach

arXiv:2203.08748 (physics)

[Submitted on 16 Mar 2022 (v1), last revised 21 Nov 2022 (this version, v2)]

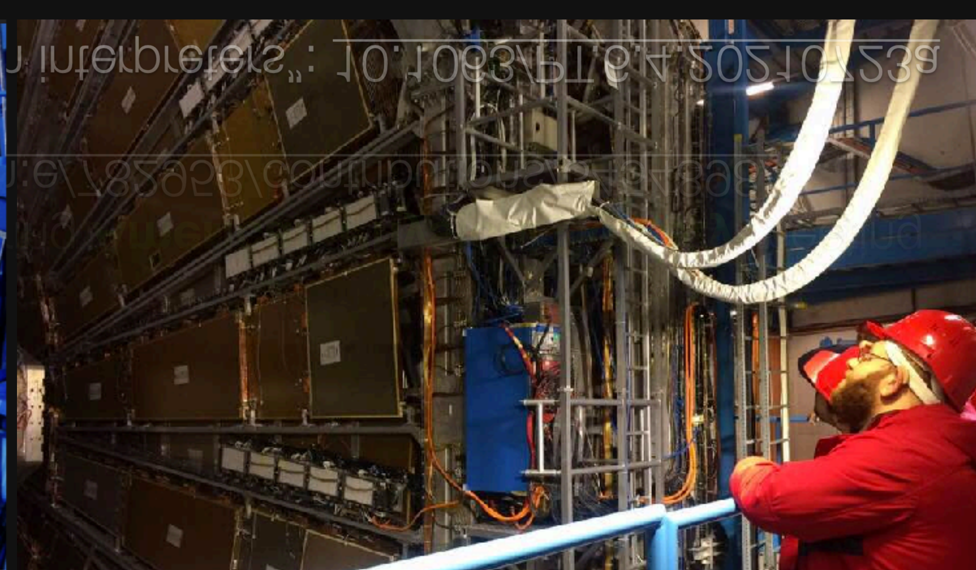
Accessibility in High Energy Physics: Lessons from the Snowmass Process

K.A. Assamagan, C. Bonifazi, J.S. Bonilla, P.A. Breur, M.-C. Chen, A. Roepe-Gier, Y.H. Lin, S. Meehan, M.E. Monzani, E. Novitski, G. Stark

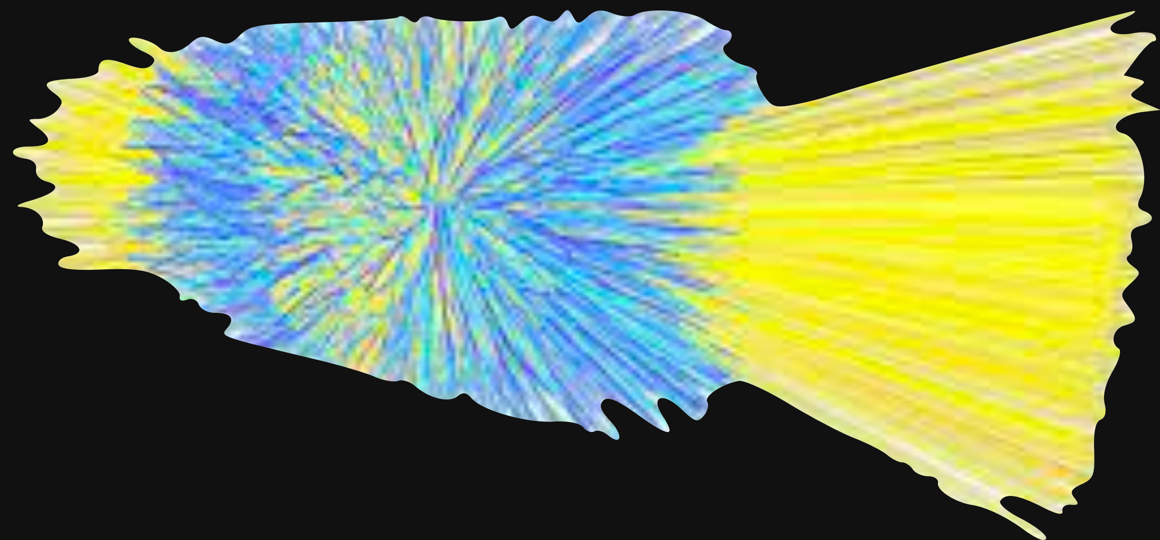
Download PDF

Accessibility to participation in the high energy physics community can be impeded by many barriers. These barriers must be acknowledged and addressed to make access more equitable in the future. An accessibility survey, the Snowmass Summer Study attendance survey, and an improved accessibility survey were sent to the Snowmass2021 community. This paper will summarize and present the barriers that prevent people from participating in the Snowmass2021 process,recommendations for the various barriers, and discussions of resources and funding needed to enact these recommendations, based on the results of all three surveys, along with personal experiences of the community members.

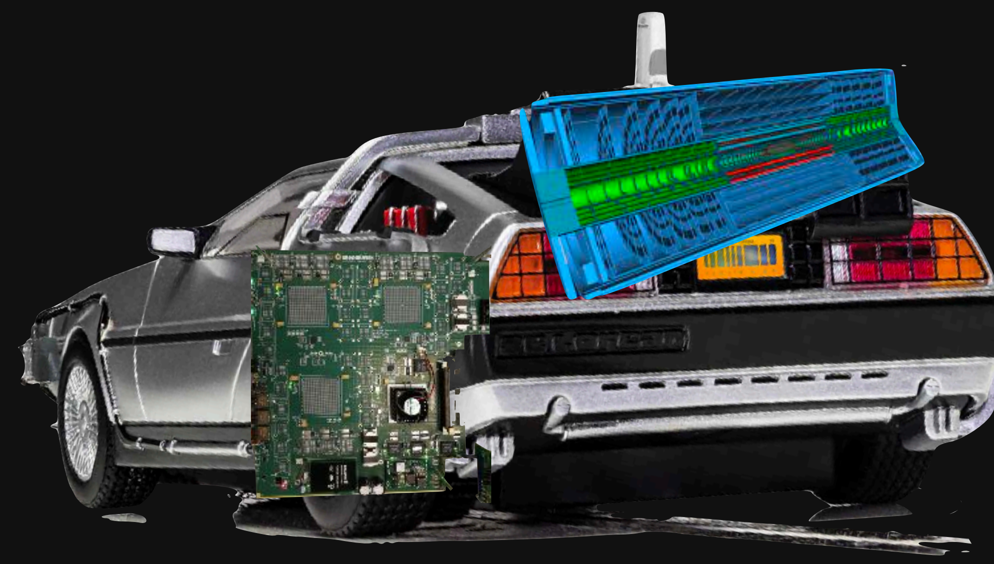
- Exhibit in ASL at the **CERN Science Gateway**: youtube.com/watch?v=BaGjAruqFec
- **CERN video** “My life as a Particle Physicist (in ASL)”: youtube.com/watch?v=3sESUT1UO6E
- **Fermilab Publication**: “A Matter of Interpretation”: symmetrymagazine.org/article/a-matter-of-interpretation-asl-physics
- "PARTY CALL PHYSICS”: Presentation during **American Physical Society** meeting about physics and accessibility: indico.cern:e/782953/contributions/3454898/
- **Physics Today**: “Deaf Scientists thrive with interpreters”: 10.1063/PT.6.4.20210723a



High-Luminosity LHC

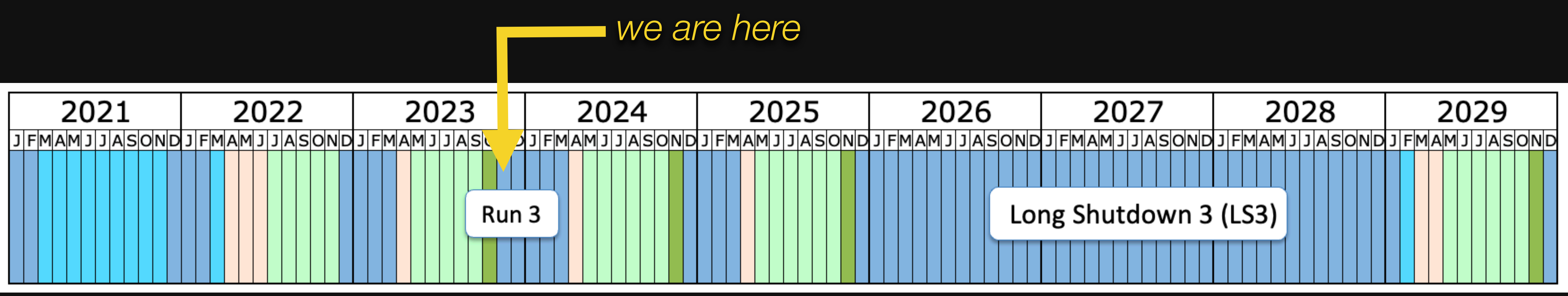


ATLAS



Looking Forward

Continuing the successful LHC physics program

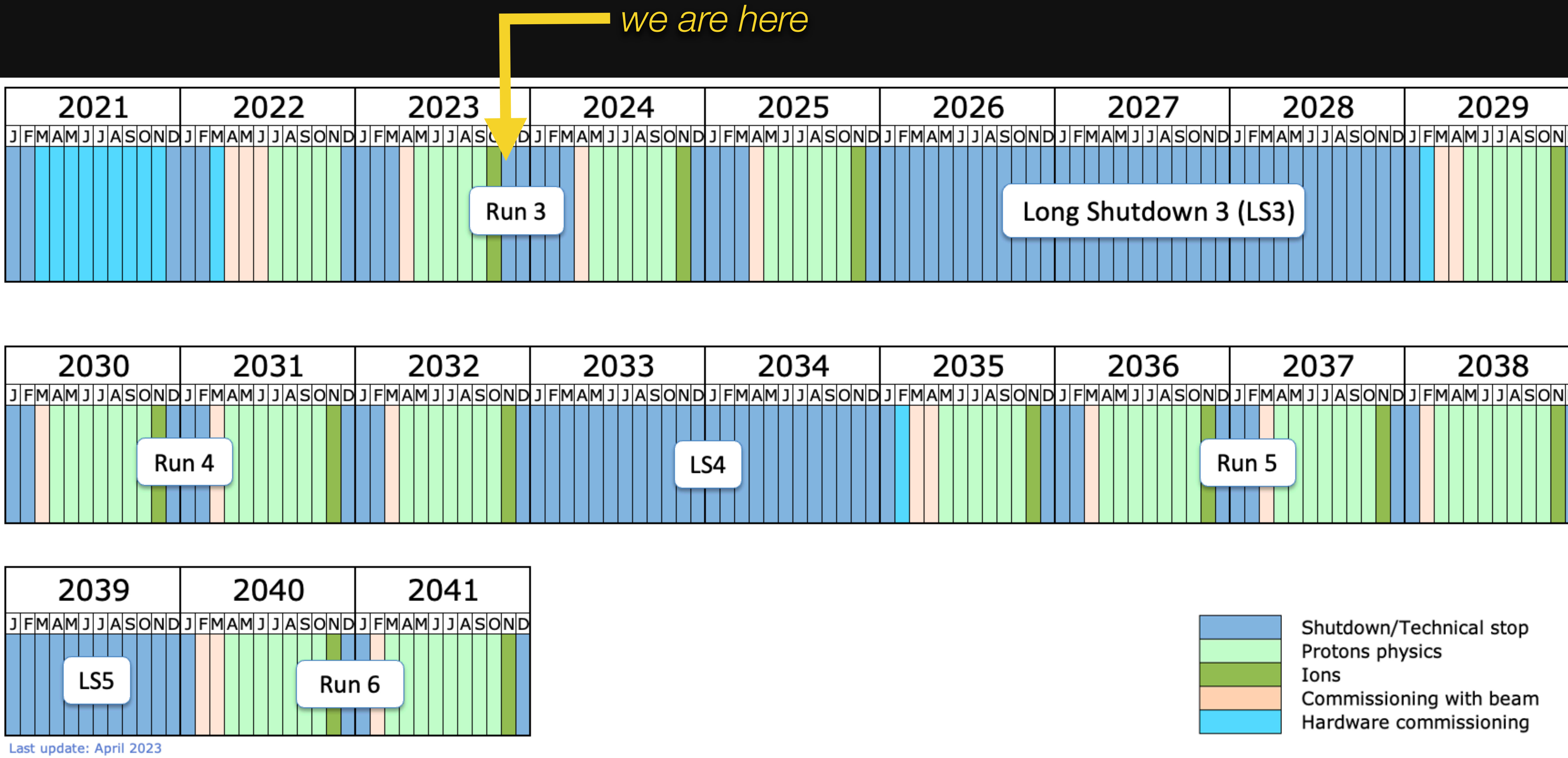


"Roads? Where we're going, we don't need roads."

— Doc Brown

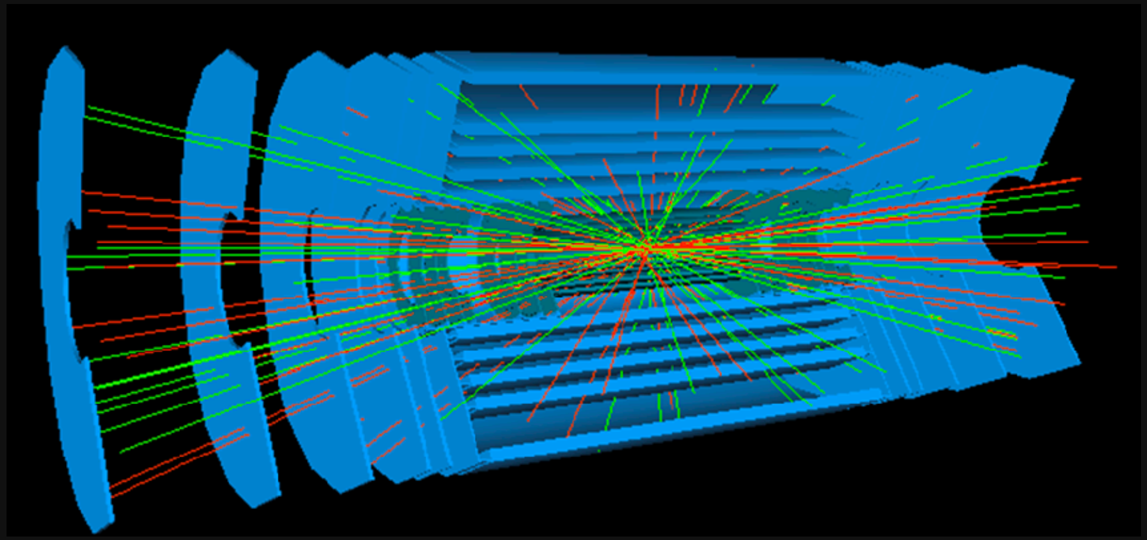
https://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-long-term.htm

The HL-LHC schedule

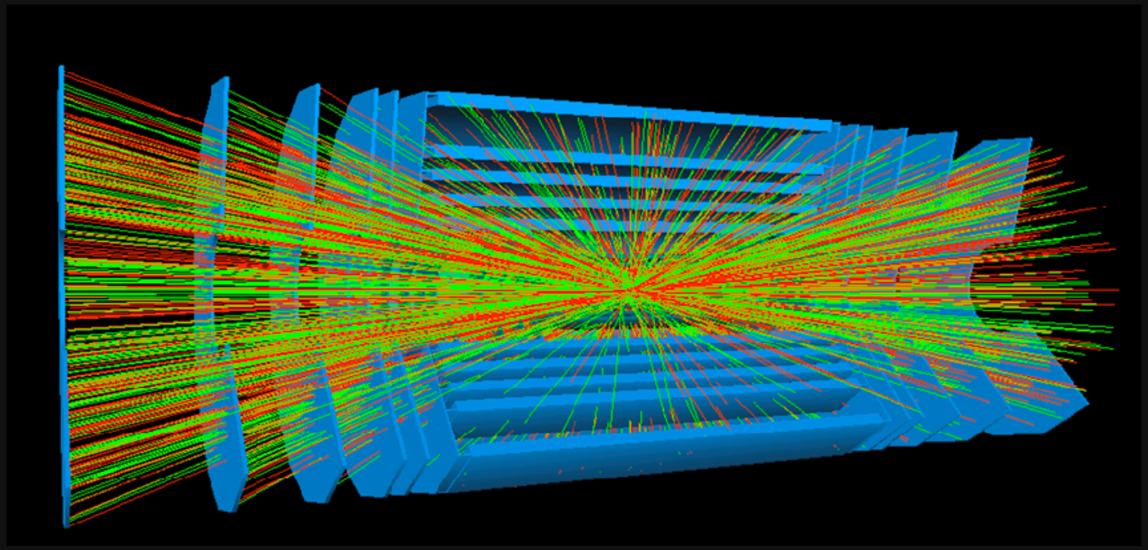


❗ ~20 more years of LHC physics, are we ready?

Strengthening our detector



$\langle \mu \rangle \approx 20$

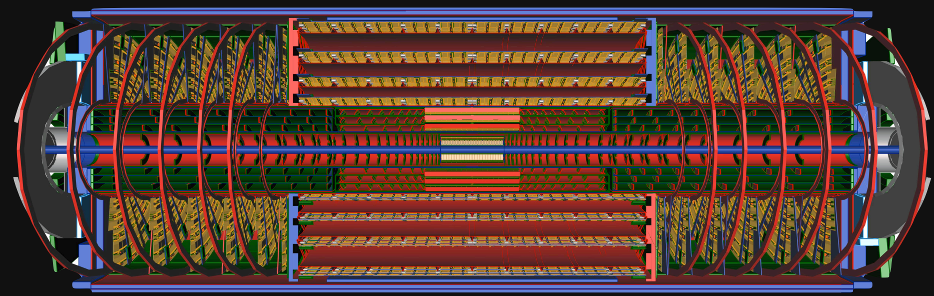


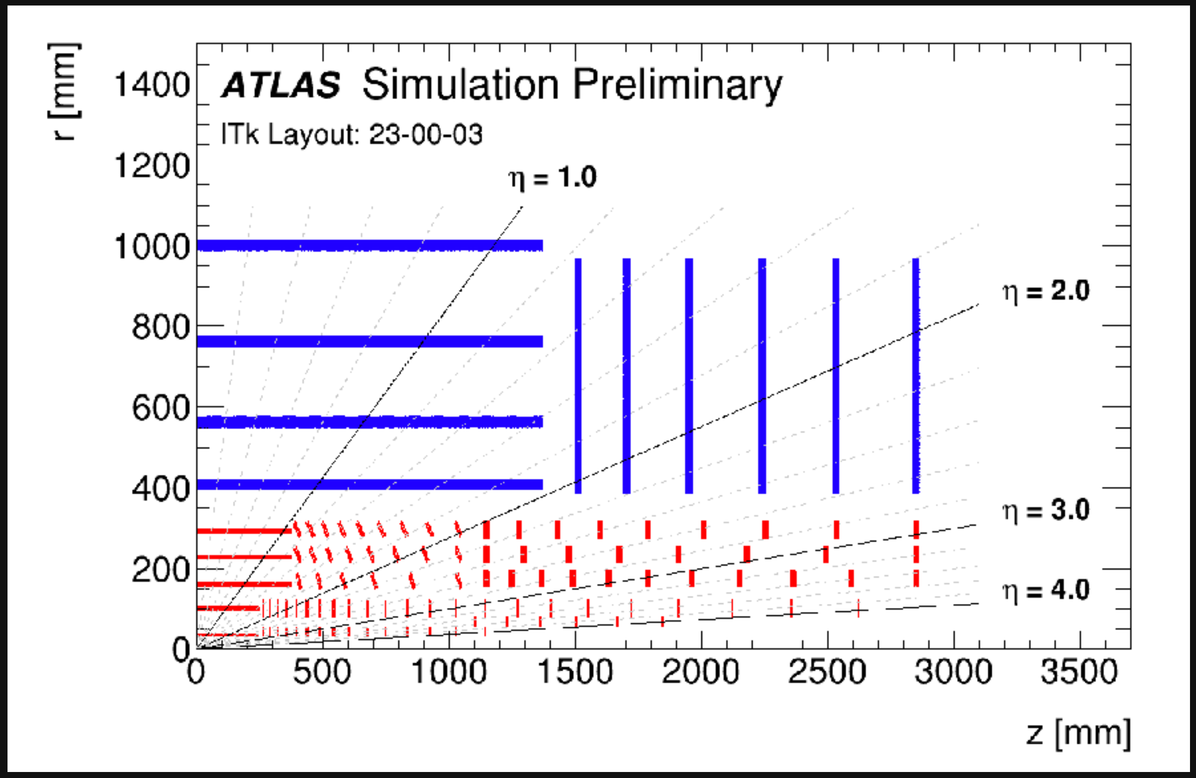
$\langle \mu \rangle \approx 200$

- Starting 2029, expect **200 simultaneous collisions**
- Requires high-throughput hardware, an **efficient trigger system**, and **radiation-tolerant tracking instrumentation** to survive
- AI/ML is everywhere, why not put it in our trigger hardware?

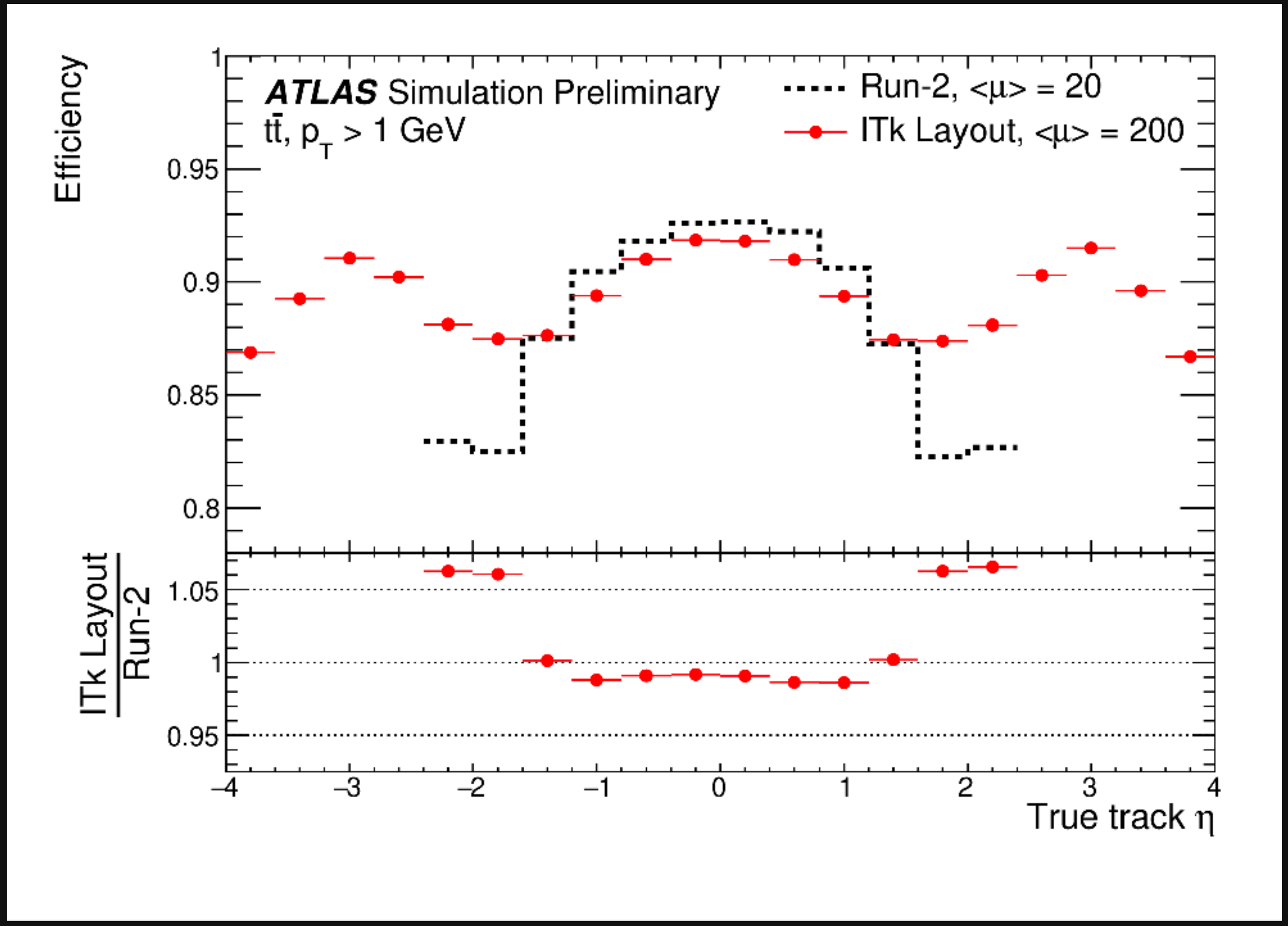
ATL-PHYS-PUB-2019-014 ATL-PHYS-PUB-2021-040

Inner TracKer (ITk)





schematic of layout



track reconstruction efficiency for $t\bar{t}$ events

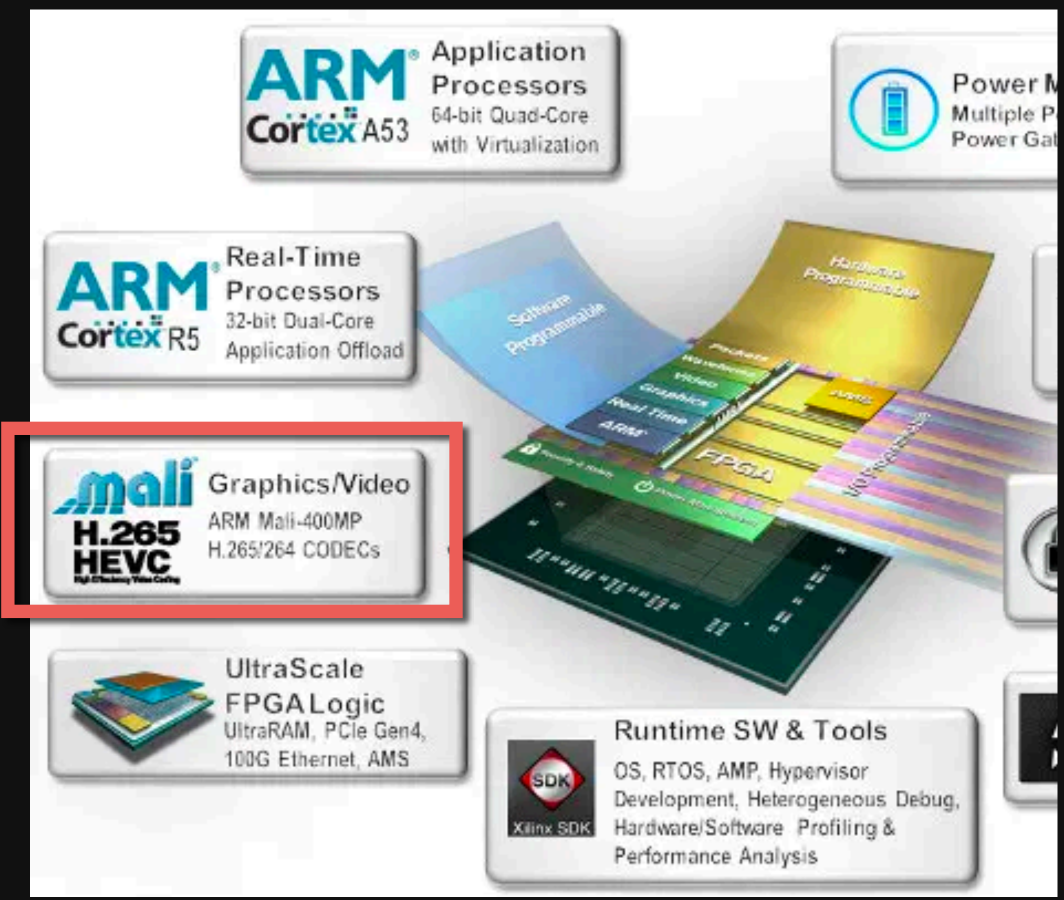
- After Run 3 (2026), **completely replace** the inner detector of the ATLAS experiment
- We need **efficient tracking** with **excellent vertex resolution**

[arXiv: 2103.05579](#) [arXiv: 2104.06622](#) [arXiv:1804.06913](#) [arXiv: 2209.01318](#)

Trigger Thoughts

Detector Layer	ITk Hit Density [mm^{-2}]	Muon Col. Hit Density [mm^{-2}]
Pixel Layer 0	0.643	3.68
Pixel Layer 1	0.22	0.51
Strip Layer 1	0.003	0.03

- We have bleeding-edge technology already installed:
  - UltraScale+ MPSoC with ARM Mali-400 MP2 GPU
- **What can we do with GPUs** in the trigger/detector?
  - Exploit tracking algorithms? Vertexing?
  - More global object reconstruction?
  - Parallelize algorithms?
- Could **information from the ITk readout chips** be used in the trigger? In addition to the calorimeter?
  - Requires low latency (bandwidth-limited?)
  - Possibly reduce front-end electronics in the detector

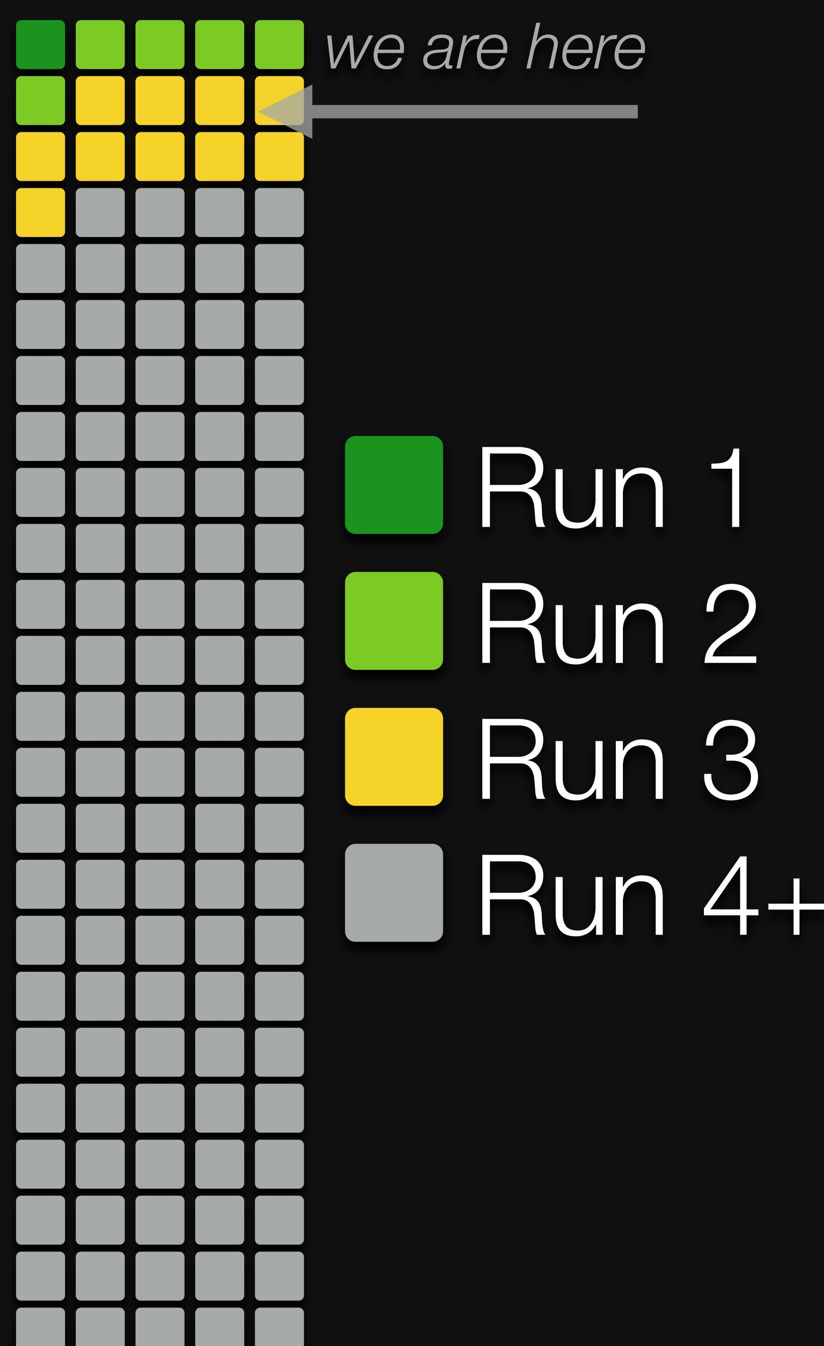


Research in this area could be exploited not only for HL-LHC, but other experiments such as μ-collider, EIC, FCC, DUNE, etc…

⚠ μ-collider, for example, needs to reject BIB hits (if it can't, it needs a trigger!)

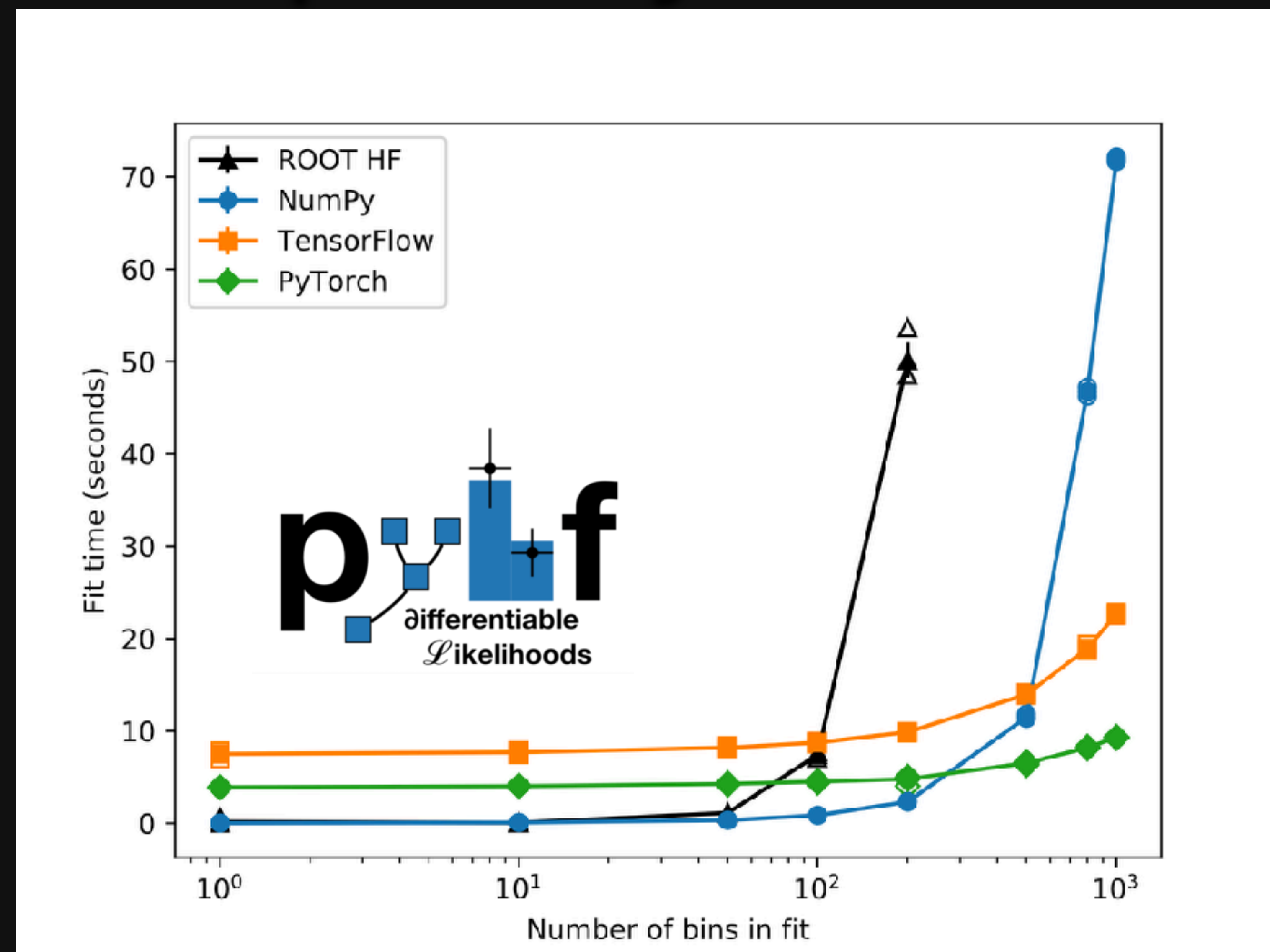
Increasing Complexity

LUMIRDLE



(each square is about 30 fb^{-1})

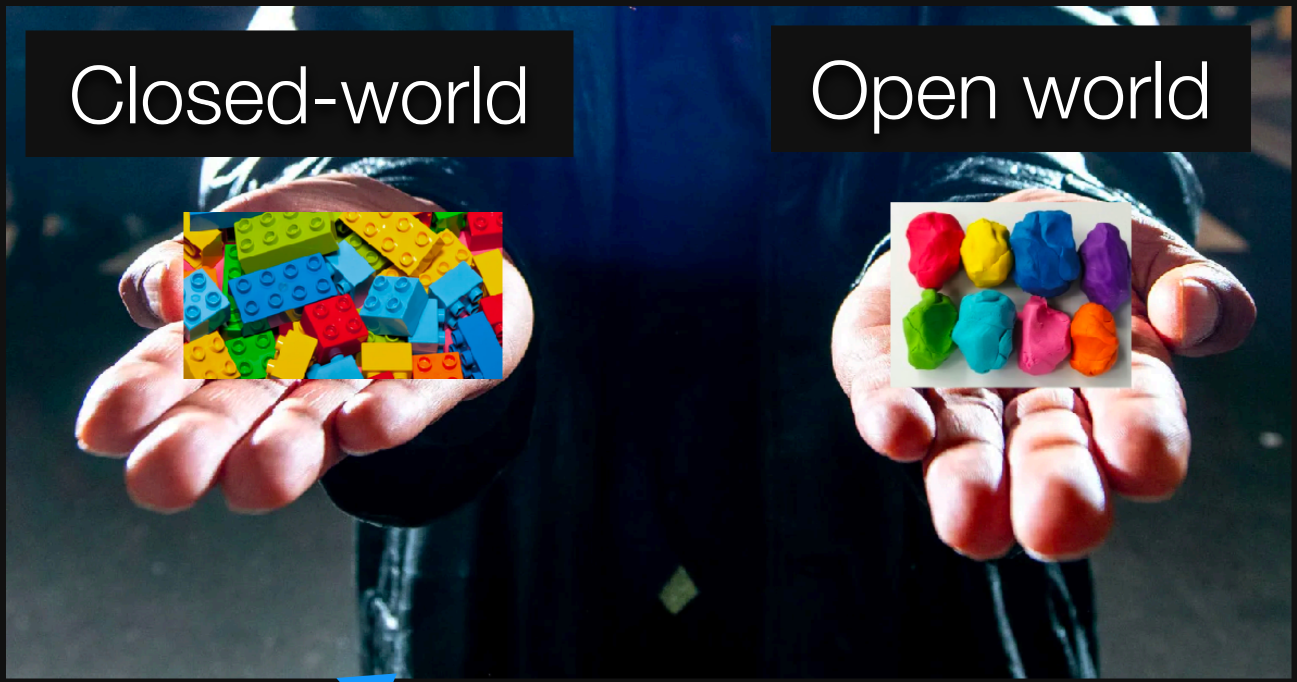
data collected



❗ Analyses will evolve in complexity. HL-LHC demands more computing resources.

Diversity of statistical models

- So, now we're at the point of the story where we've got **all the important pieces in place**… except
  - what analysis do we want to publish? **All of them?**
  - arbitrary likelihood functions? Need common tools across experiments!
- This gives us two paths forward:
  - "**closed-world**" implementation: build statistical models from a finite set of building blocks (e.g. linear combinations of Gaussian and Poisson distributions)
  - "**open-world**" implementation: anything goes! This needs work.



pyhf
∂ifferentiable
ℒikelihoods

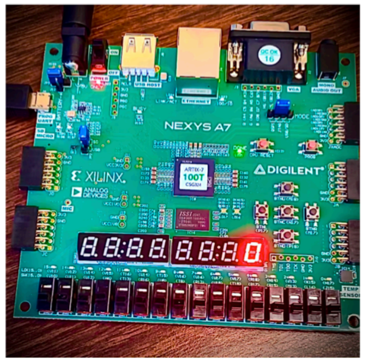
the next step

Open World Applications!

Phys 476: Modern Electronics for Physicists
Spring semester 2025

Instructor
- **Name:** Prof. Keisuke Yoshihara
- **Email:** kyoshiha@hawaii.edu

Class Information
- **Classroom/Lab:** WAT415
- **Class Hours:**
  - **Tuesday:** 1:30 PM – 4:50 PM [Lecture + Lab]
  - **Thursday:** 1:30 PM – 3:20 PM [Lecture]

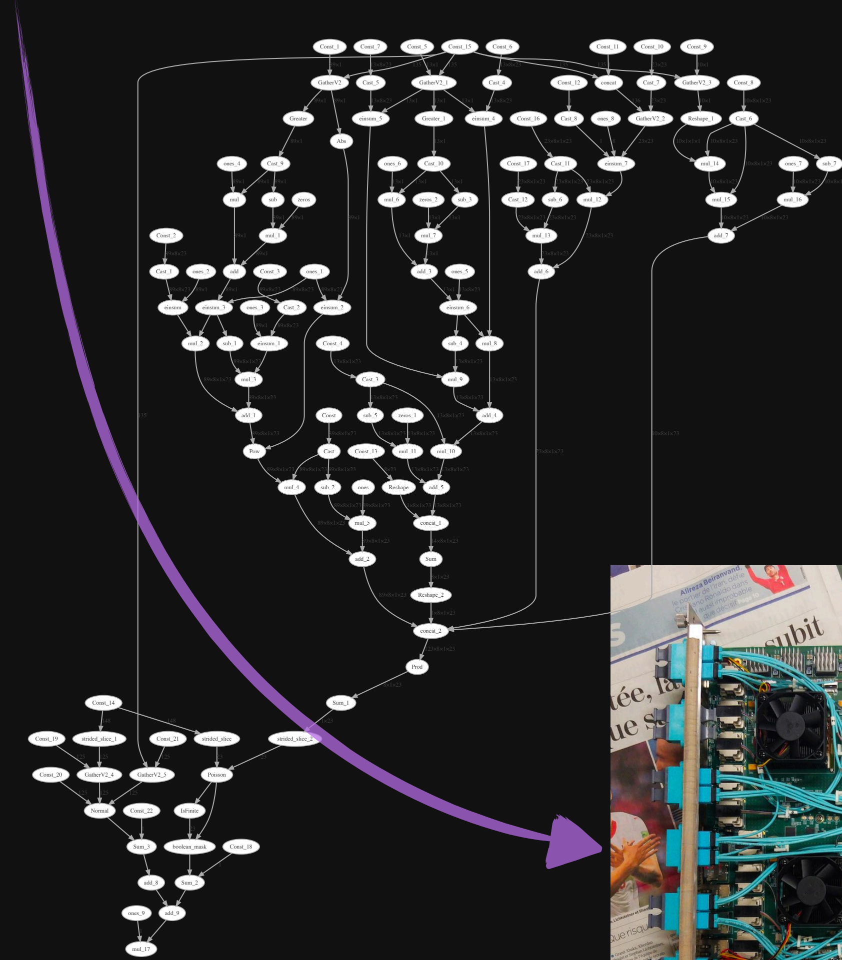


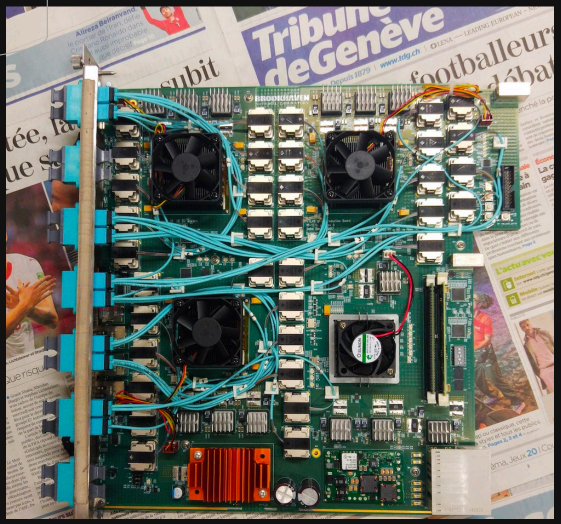
FPGA Board

Course Goals
This course is designed for beginners who want to explore Digital Circuit Design and gain essential skills in:
- HDL-based FPGA Programming
- ML/AI Development with Python
- Implementing ML/AI on FPGAs with High-Level Synthesis (HLS) tools to deploy ML/AI models on FPGAs.
- **Applications in Particle Physics Experiments**

Syllabus

$$f(\boldsymbol{n}, \boldsymbol{a} \mid \boldsymbol{\eta}, \boldsymbol{\chi}) = \underbrace{\prod_{c \in \text{channels}} \prod_{b \in \text{bins}_c} \text{Pois}\left(n_{cb} \mid \nu_{cb}(\boldsymbol{\eta}, \boldsymbol{\chi})\right)}_{\text{Simultaneous measurement of multiple channels}} \underbrace{\prod_{\chi \in \mathcal{X}} c_\chi(a_\chi \mid \chi)}_{\text{constraint terms for "auxiliary measurements"}},$$





- FPGAs are better suited than GPUs for statistical fits
  - SMEFT? flavor physics? global fits?

probability models → computational graph → FPGA

Conclusion

- What will the future bring?
  - Run 3 is now!
  - Run 4+ in 2029
  - Other colliders?
- A rich physics and hardware program
  - Lots of opportunities for students to work on instrumentation, data analysis, and software development
- Provide ways to recycle analyses and test new ideas
  - Collaborations need to provide enough data for re-use
  - Develop new techniques for models with challenging signatures
- Continue to improve accessibility through preservation/reproducibility as well as teaching/promoting inclusive practices
  - A rising tide lifts all boats.
- Identify uncovered areas and find new rocks to look under for new physics