UCI School of Physical Sciences | BRILLIANT FUTURE THE CAMPAIGN FOR UCI

DISCOVERING THE UNIVERSE: THE FASER EXPERIMENT AT THE LHC

Jonathan Feng, Department of Physics and Astronomy
Celebrate Physical Sciences, 15 May 2021

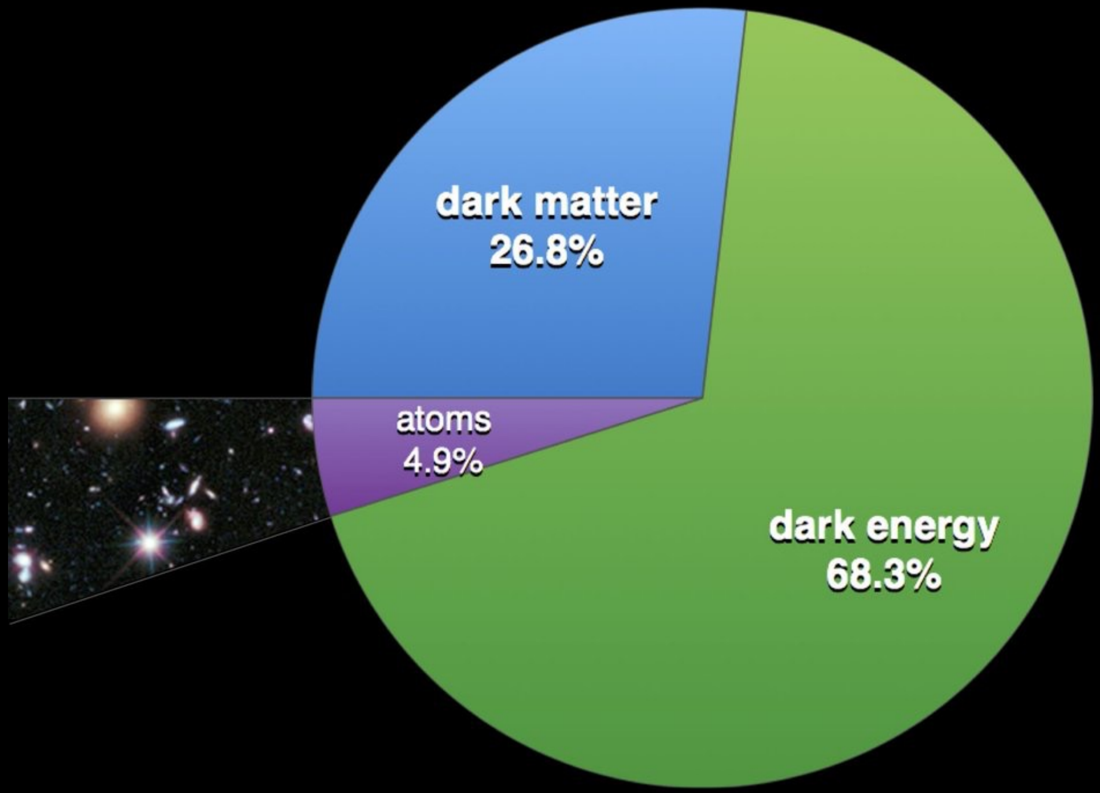
WELCOME!

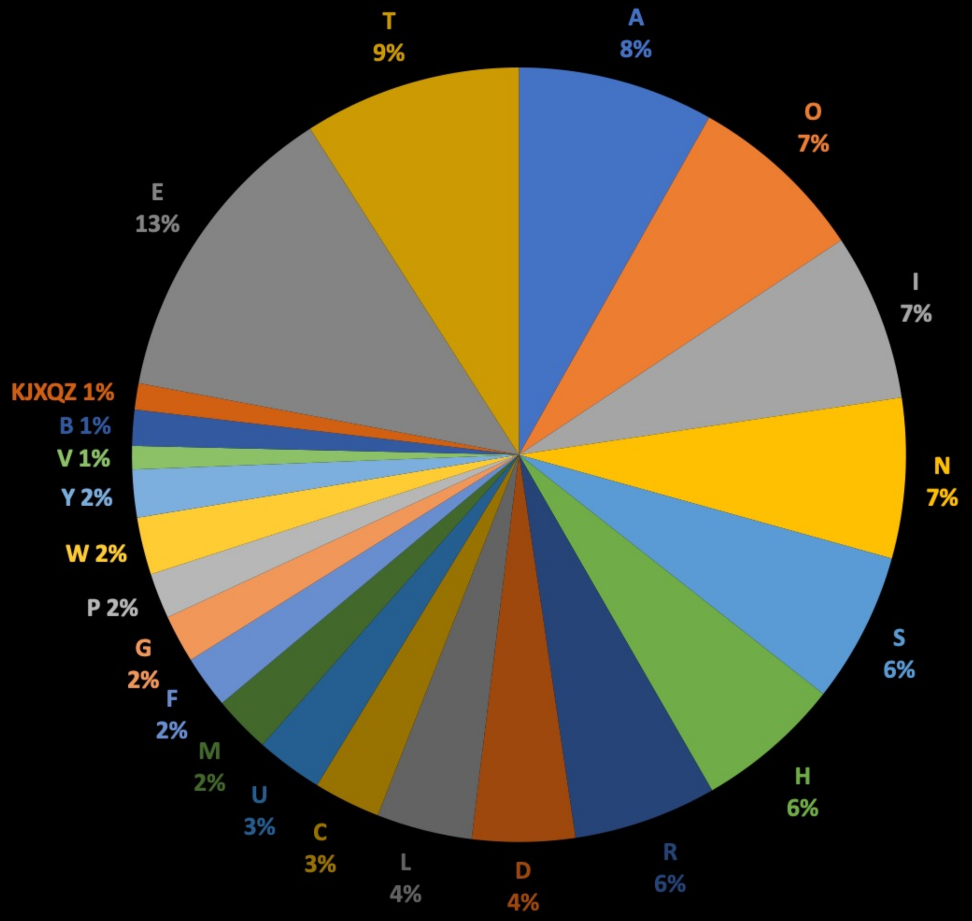
- I've been at UCI since 2002

- P&A Courses Taught
  - 7D: Electricity and Magnetism
  - 7E: Oscillations, Waves, and Optics
  - 60: Thermal Physics
  - H90: The Physics of Sound and Light
  - 116: Relativity and Black Holes
  - 136: Introduction to Particle Physics
  - 234AB: Elementary Particle Physics
  - 235AB: Quantum Field Theory

- Please jump in with questions, despite the webinar format.

THE UNIVERSE TODAY





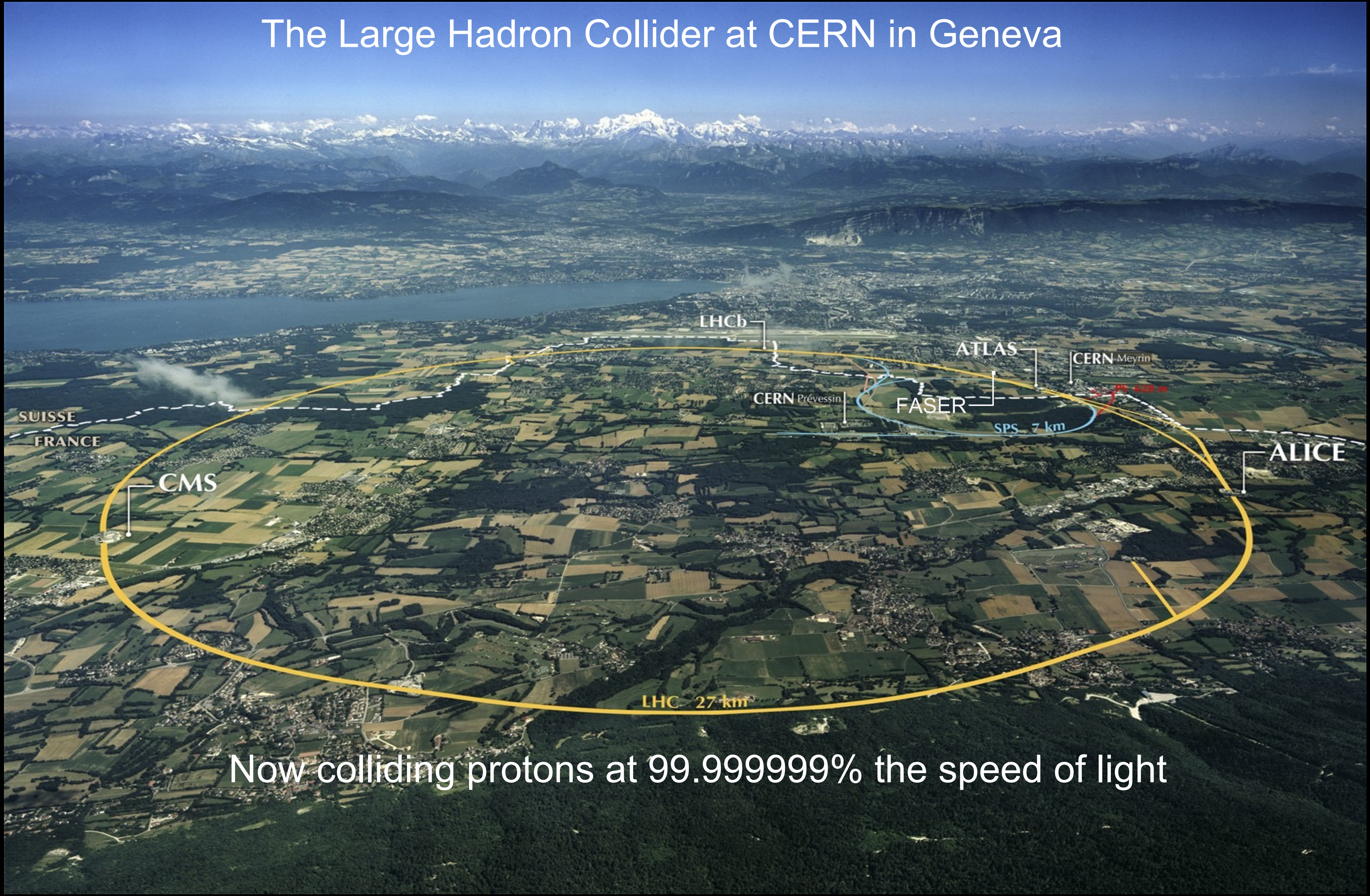
- Trying to understand the universe knowing only what we know today is like trying to understand the English language knowing only the letters V, Y, and W.
- We need to discover the rest of the alphabet!

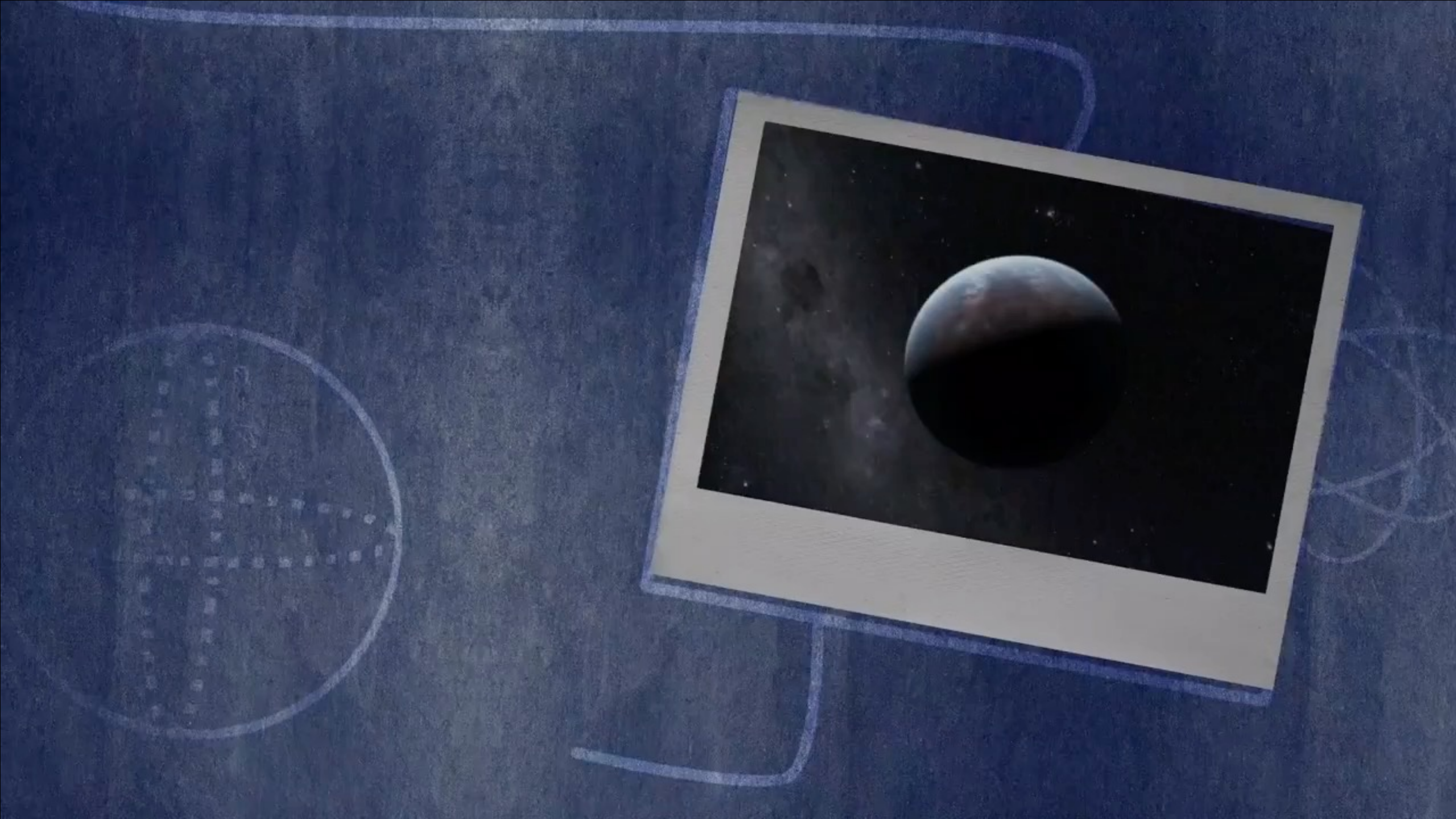
PARTICLE ACCELERATORS AND COLLIDERS

- To discover new forms of matter, the workhorse tool has been particle colliders: we accelerate electrons and protons, smash them together, and see what comes out.

- The first accelerator: Ernest Lawrence in the 1930's
- Bigger accelerators: higher energies, heavier particles

THE LATEST REALIZATION OF LAWRENCE'S VISION

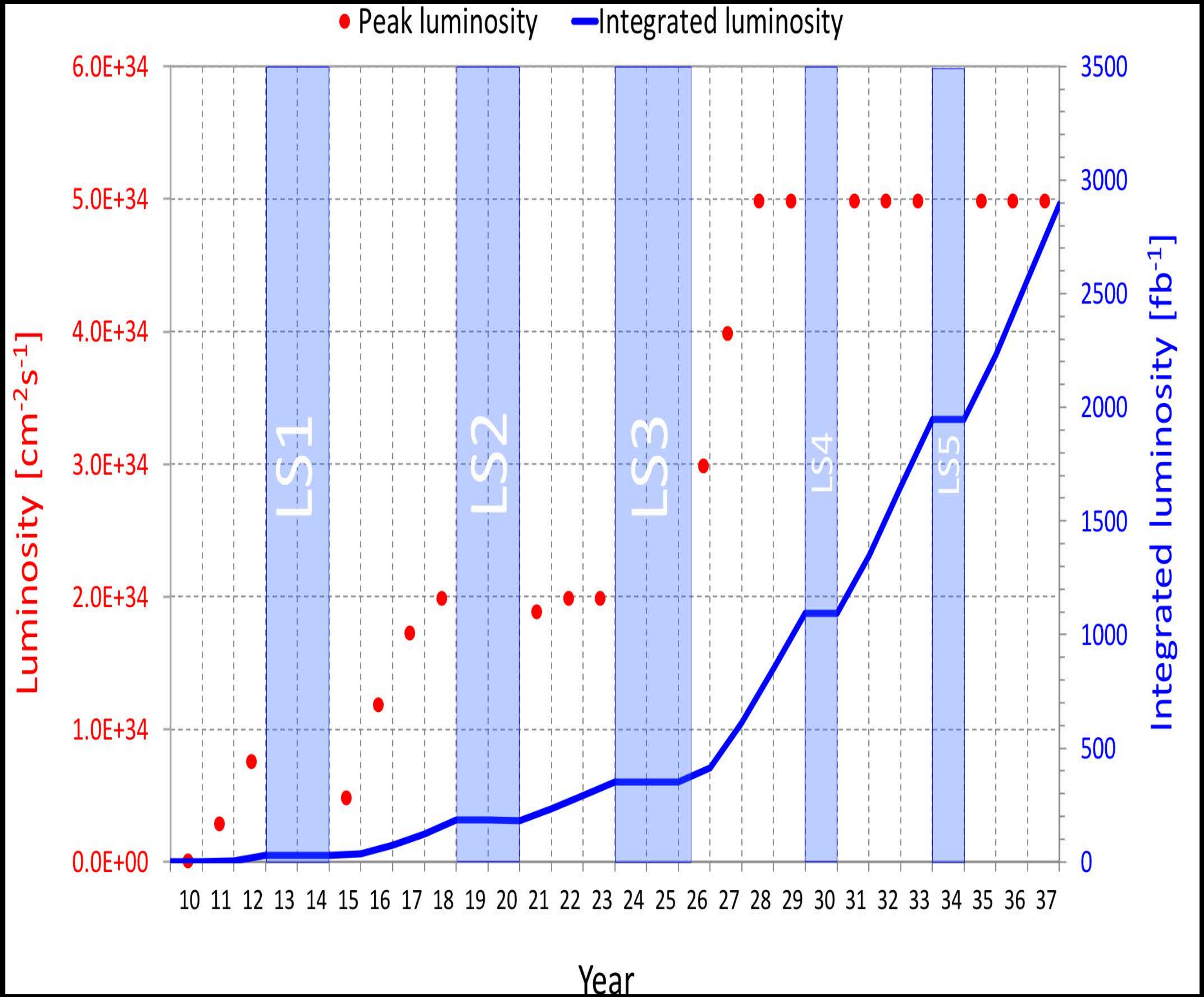




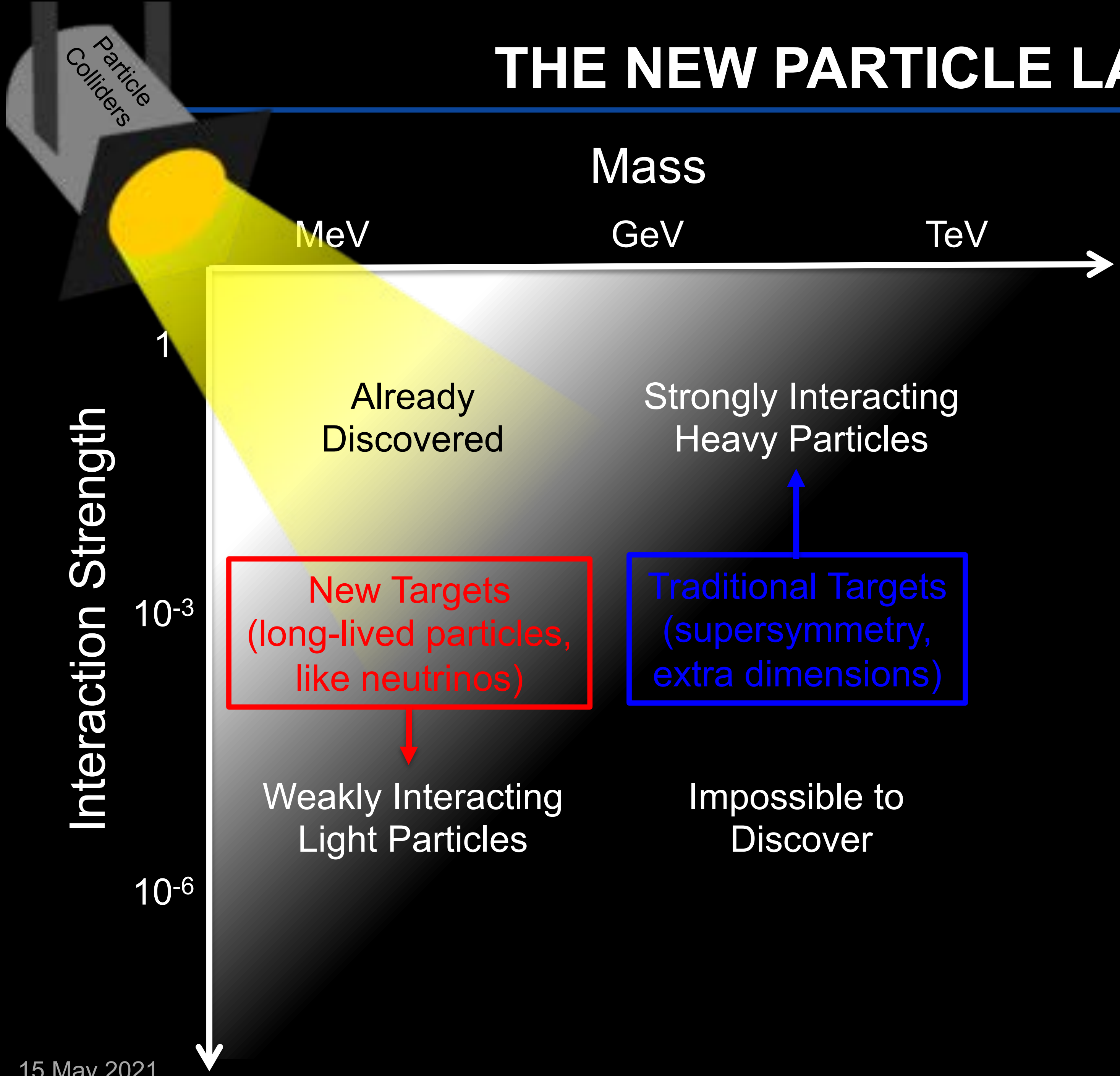
LARGE HADRON COLLIDER: CURRENT STATUS

- The discovery of the Higgs boson in 2012 completed the standard model of particle physics, but so far there is no evidence for other new particles.

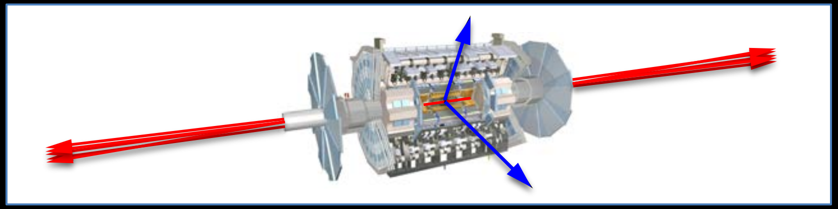
- The LHC is currently shut down for upgrades. COVID has delayed the re-opening by a year, but the LHC will start again in 2022 and run until 2037.



THE NEW PARTICLE LANDSCAPE



- In 2017, our group at UCI noticed that weakly interacting, light particles are dominantly produced along the beamline:

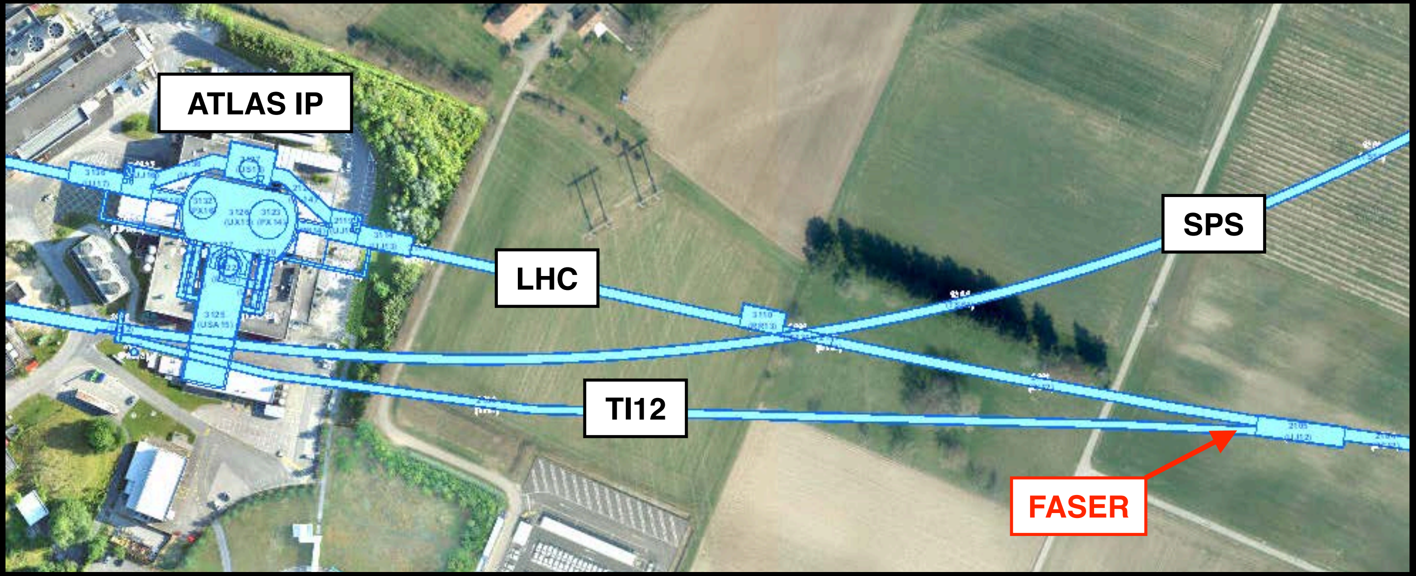


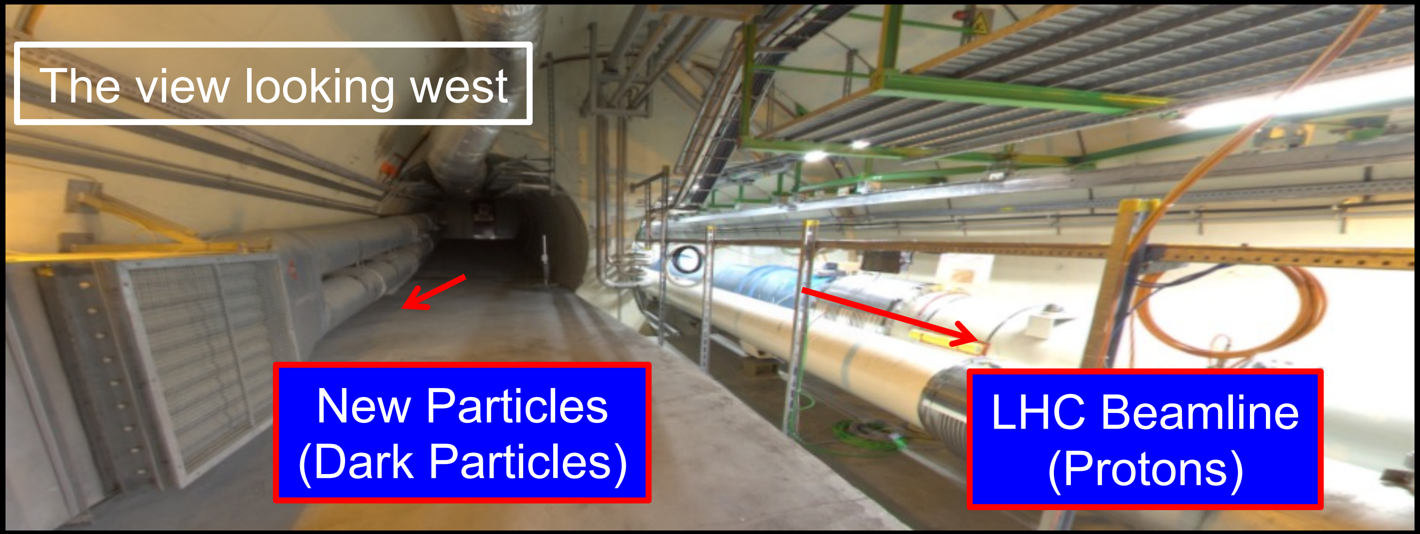
- But existing detectors have holes along the beamline, and so are almost perfectly designed **not** to discover these particles.

A SOLUTION

- We can't put a detector on the beamline – it will stop the protons.
- But if we go far down the beamline, the LHC beam will curve away, while the new weakly interacting particles which go straight.
- We can discover new particles in this far-forward region – and there is an existing tunnel there, 480 m downstream!

Feng, Galon, Kling, Trojanowski (2017)





PATH OF DARK PARTICLES FROM ATLAS TO FASER

Dougherty, CERN Integration (2019)

FORWARD SEARCH EXPERIMENT

- It turns out that a relatively cheap, small, and fast experiment placed in the existing tunnel can provide the most sensitive searches to date for many kinds of new particles.

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

Feng, Galon, Kling, Trojanowski (2017)

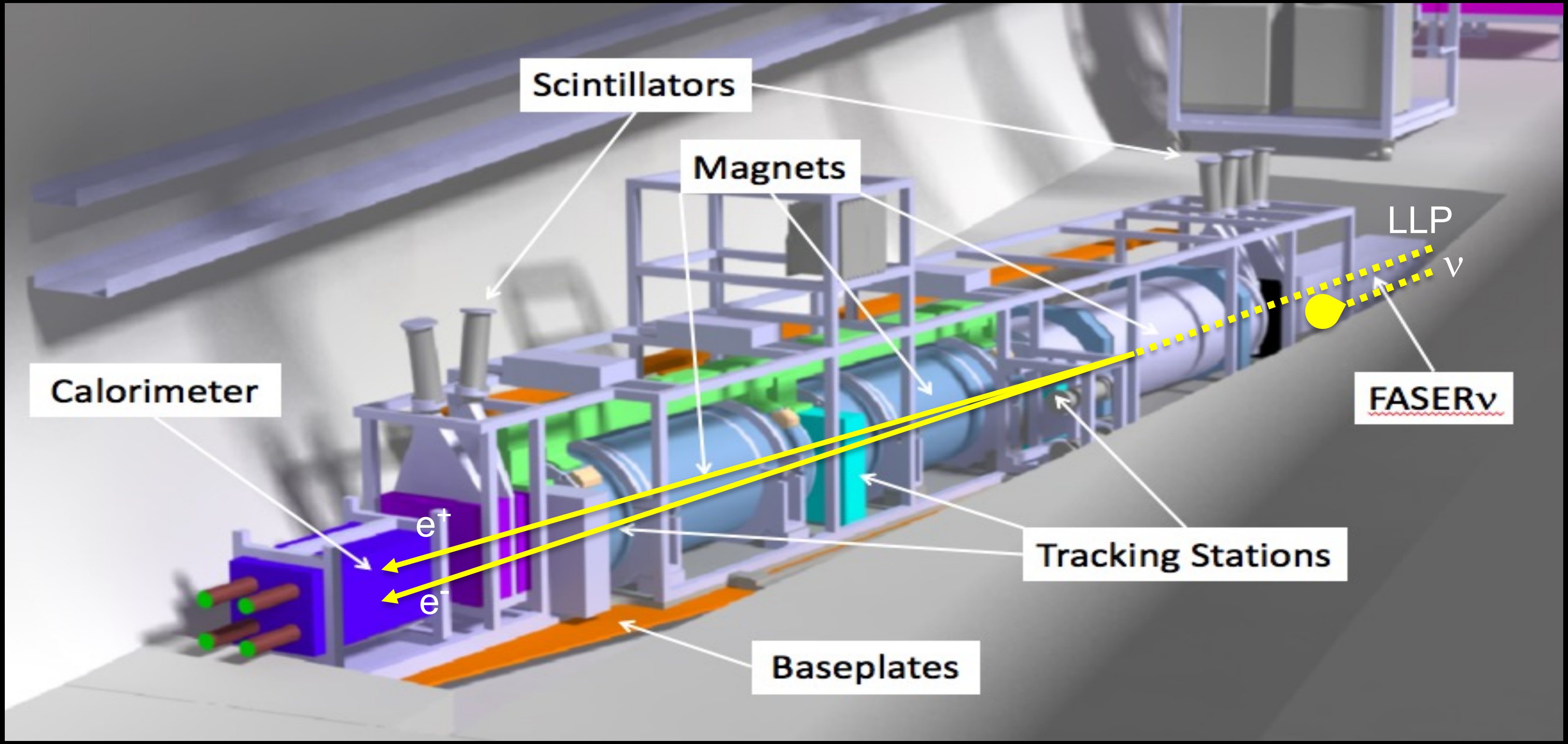
THE FASER COLLABORATION NOW

71 collaborators, 20 institutions, 8 countries

Henso Abreu (Technion), Yoav Afik (Technion), Claire Antel (Geneva), Akitaka Ariga (Chiba/Bern), Tomoko Ariga (Kyushu/Bern), Florian Bernlochner (Bonn), Tobias Boeckh (Bonn), Jamie Boyd (CERN), Lydia Brenner (CERN), Franck Cadoux (Geneva), Dave Casper (UC Irvine), Charlotte Cavanagh (Liverpool), Xin Chen (Tsinghua), Andrea Coccaro (INFN), Monica D'Onofrio (Liverpool), Candan Dozen (Tsinghua), Yannick Favre (Geneva), Deion Fellers (Oregon), Jonathan Feng (UC Irvine), Didier Ferrere (Geneva), Stephen Gibson (Royal Holloway), Sergio Gonzalez-Sevilla (Geneva), Carl Gwilliam (Liverpool), Shih-Chieh Hsu (Washington), Zhen Hu (Tsinghua), Peppe Iacobucci (Geneva), Tomohiro Inada (Tsinghua), Sune Jakobsen (CERN), Enrique Kajomovitz (Technion), Felix Kling (SLAC), Umut Kose (CERN), Susanne Kuehn (CERN), Helena Lefebvre (Royal Holloway), Lorne Levinson (Weizmann), Ke Li (Washington), Jinfeng Liu (Tsinghua), Chiara Magliocca (Geneva), Josh McFayden (CERN), Dimitar Mladenov (CERN), Mitsuhiro Nakamura (Nagoya), Toshiyuki Nakano (Nagoya), Marzio Nessi (CERN), Friedemann Neuhaus (Mainz), Laurie Nevay (Royal Holloway), Hidetoshi Otono (Kyushu), Lorenzo Paolozzi (Geneva), Carlo Pandini (Geneva), Hao Pang (Tsinghua), Brian Petersen (CERN), Francesco Pietropaolo (CERN), Johanna Price (UC Irvine), Markus Prim (Bonn), Michaela Queitsch-Maitland (CERN), Filippo Resnati (CERN), Chiara Rizzi (Geneva), Hiroki Rokujo (Nagoya), Jakob Salfeld-Nebgen (CERN), Osamu Sato (Nagoya), Paola Scampoli (Bern), Kristof Schmieden (Mainz), Matthias Schott (Mainz), Anna Sfyrla (Geneva), Savannah Shively (UC Irvine), John Spencer (Washington), Yosuke Takubo (KEK), Ondrej Theiner (Geneva), Eric Torrence (Oregon), Serhan Tufanli (CERN), Benedikt Vormvald (CERN), Di Wang (Tsinghua), Gang Zhang (Tsinghua)

THE SIGNAL – WHAT WE ARE LOOKING FOR

- Nothing comes in, but 2 ~TeV, opposite-charged tracks are created, which point back to the ATLAS interaction point: a "light shining through (100 m-thick) wall," background-free experiment.
- Scintillators veto incoming charged tracks (muons), and permanent dipole magnets split the charged tracks, which are detected by 3 tracking stations and a calorimeter.



PREPARING THE TUNNEL FOR FASER

- The beam collision axis has been located to mm accuracy by the CERN survey department. To place FASER on this axis, a trench was required to lower the floor by 46 cm.

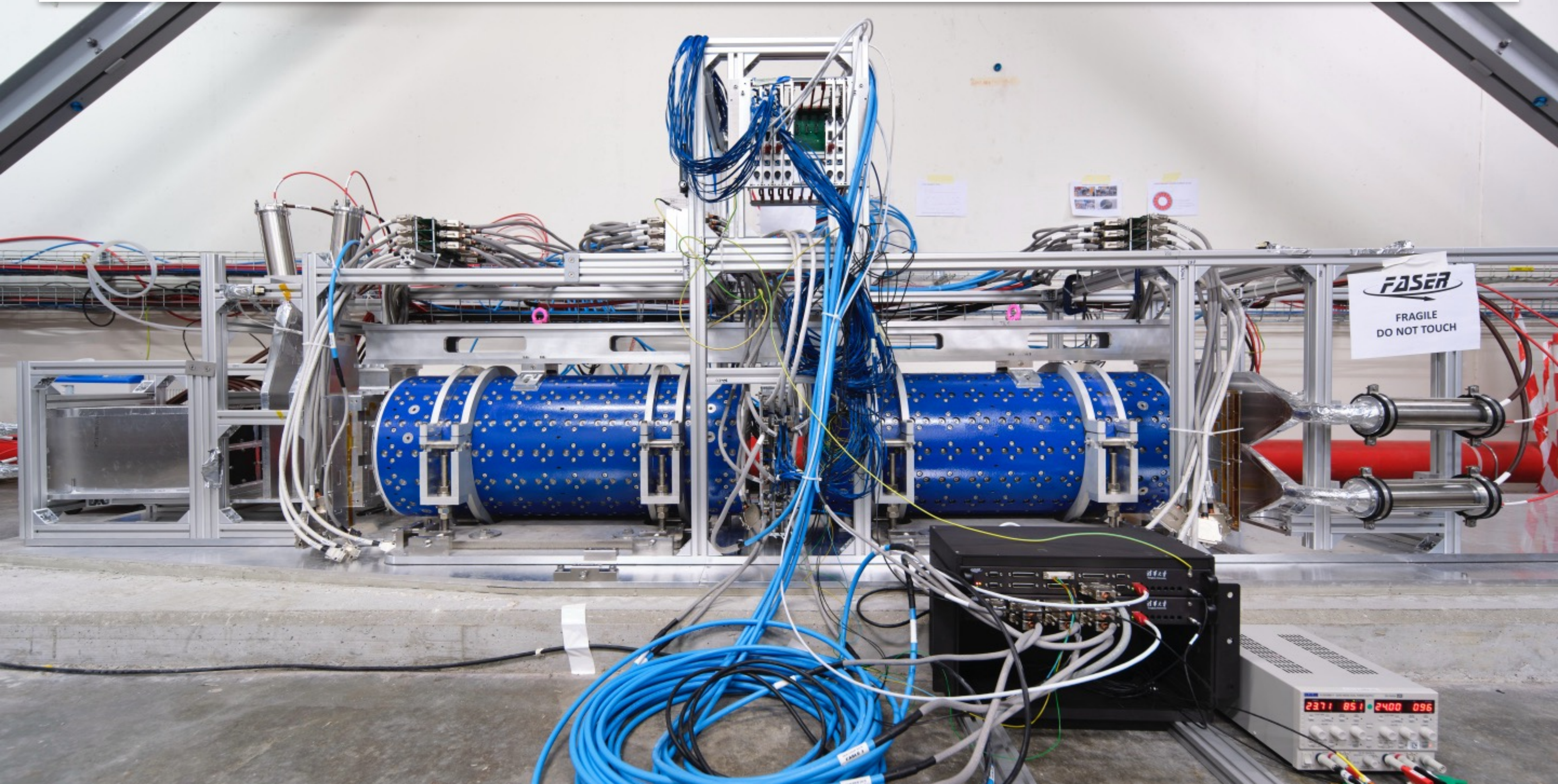
- The trench was completed by an Italian firm just hours before COVID shut down CERN in March 2020.


2019


Spring 2020

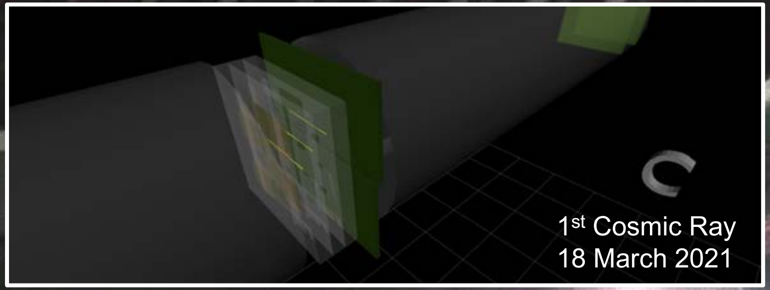

Summer 2020

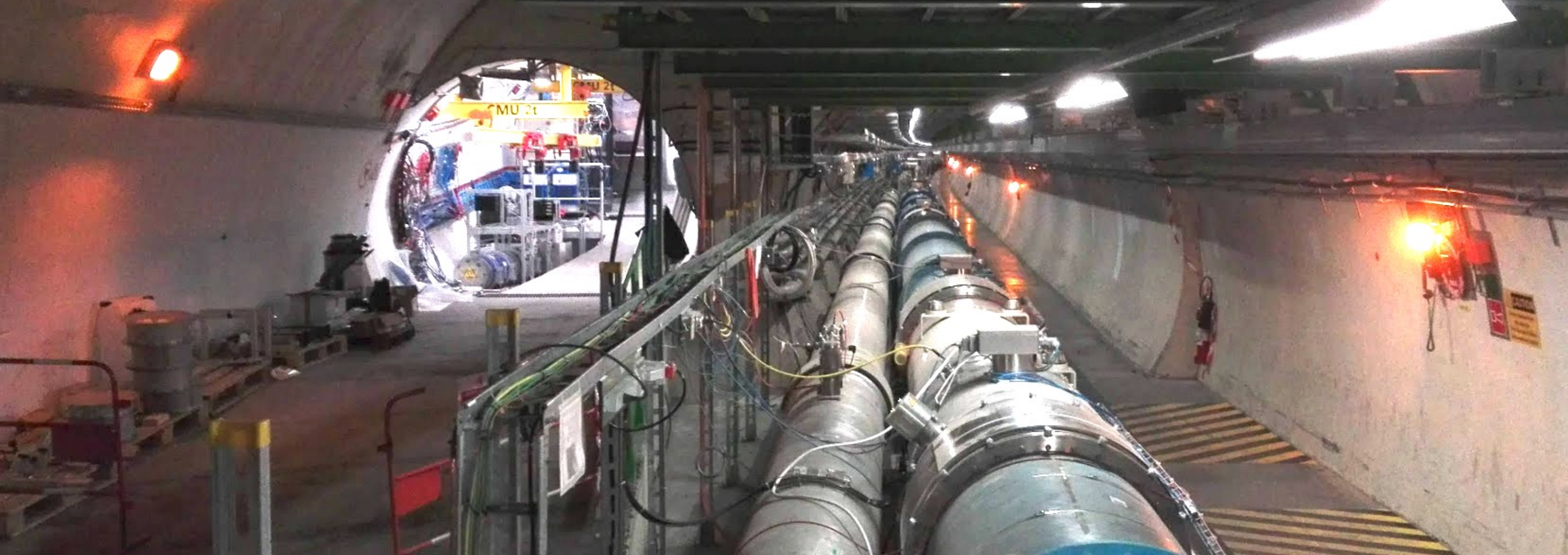
CONSTRUCTION AND COMMISSIONING ON THE SURFACE



FASER INSTALLATION IN THE LHC TUNNEL

- Installation completed in March 2021
- Commissioning with cosmic rays ongoing
- Data taking begins in April 2022 when the LHC turns on





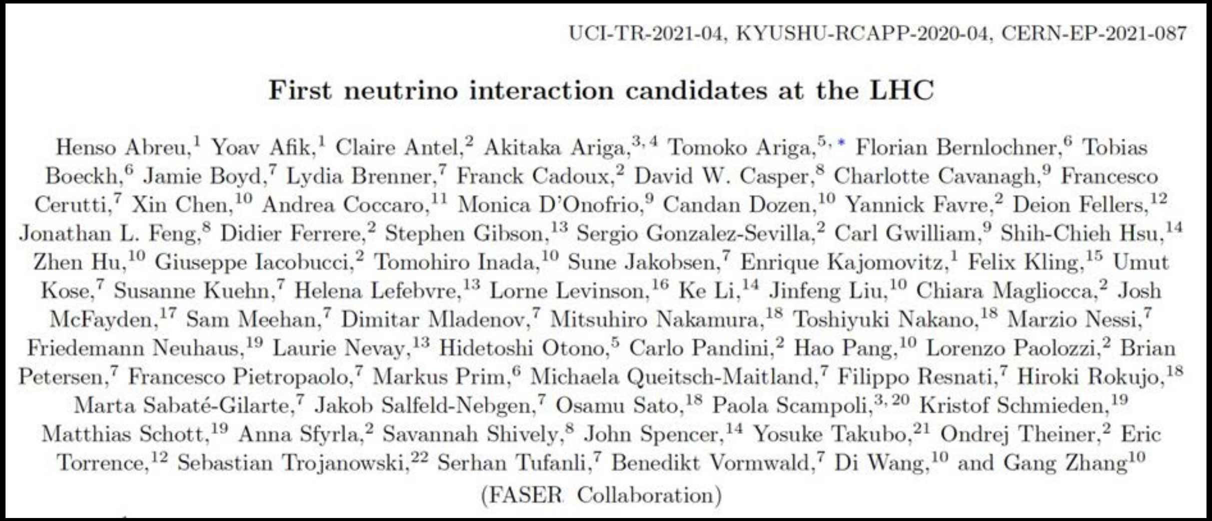
FIRST COLLIDER NEUTRINOS

- We are looking for new light and weakly interacting particles, but there are also known light and weakly-interacting particles: neutrinos.

- No collider neutrino has ever been detected, because the highest-energy, most-detectable ones are produced along the beamline in the far forward direction.

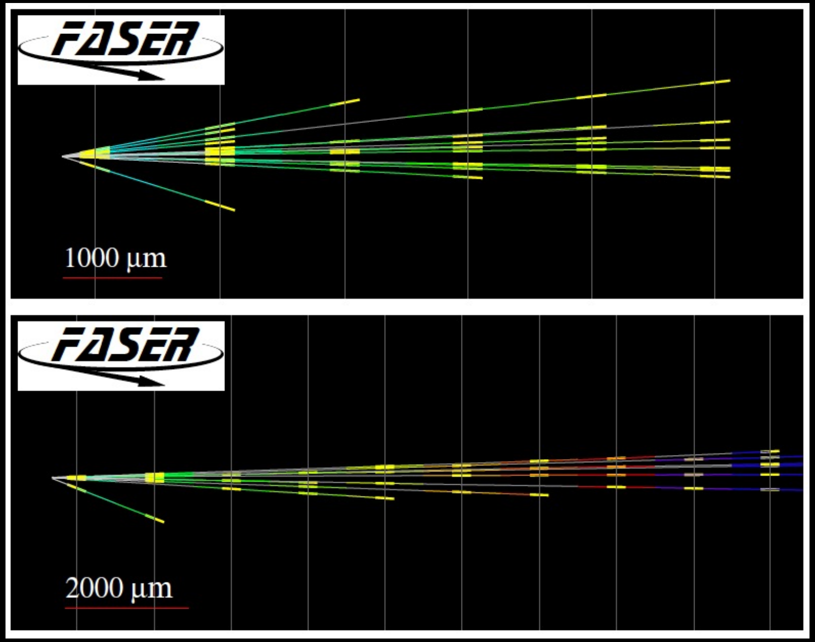
- In 2018, we placed a 29 kg pilot detector in the far forward region for 4 weeks.

- On 14 May 2021, we announced the first direct detection of neutrino candidates produced at a collider. A promising sign of things to come!


UCI-TR-2021-04, KYUSHU-RCAPP-2020-04, CERN-EP-2021-087

First neutrino interaction candidates at the LHC

Henso Abreu,[1] Yoav Afik,[1] Claire Antel,[2] Akitaka Ariga,[3,4] Tomoko Ariga,[5,*] Florian Bernlochner,[6] Tobias Boeckh,[6] Jamie Boyd,[7] Lydia Brenner,[7] Franck Cadoux,[2] David W. Casper,[8] Charlotte Cavanagh,[9] Francesco Cerutti,[7] Xin Chen,[10] Andrea Coccaro,[11] Monica D'Onofrio,[9] Candan Dozen,[10] Yannick Favre,[2] Deion Fellers,[12] Jonathan L. Feng,[8] Didier Ferrere,[2] Stephen Gibson,[13] Sergio Gonzalez-Sevilla,[2] Carl Gwilliam,[9] Shih-Chieh Hsu,[14] Zhen Hu,[10] Giuseppe Iacobucci,[2] Tomohiro Inada,[10] Sune Jakobsen,[7] Enrique Kajomovitz,[1] Felix Kling,[15] Umut Kose,[7] Susanne Kuehn,[7] Helena Lefebvre,[13] Lorne Levinson,[16] Ke Li,[14] Jinfeng Liu,[10] Chiara Magliocca,[2] Josh McFayden,[17] Sam Meehan,[7] Dimitar Mladenov,[7] Mitsuhiro Nakamura,[18] Toshiyuki Nakano,[18] Marzio Nessi,[7] Friedemann Neuhaus,[19] Laurie Nevay,[13] Hidetoshi Otono,[5] Carlo Pandini,[2] Hao Pang,[10] Lorenzo Paolozzi,[2] Brian Petersen,[7] Francesco Pietropaolo,[7] Markus Prim,[6] Michaela Queitsch-Maitland,[7] Filippo Resnati,[7] Hiroki Rokujo,[18] Marta Sabaté-Gilarte,[7] Jakob Salfeld-Nebgen,[7] Osamu Sato,[18] Paola Scampoli,[3,20] Kristof Schmieden,[19] Matthias Schott,[19] Anna Sfyrla,[2] Savannah Shively,[8] John Spencer,[14] Yosuke Takubo,[21] Ondrej Theiner,[2] Eric Torrence,[12] Sebastian Trojanowski,[22] Serhan Tufanli,[7] Benedikt Vormwald,[7] Di Wang,[10] and Gang Zhang[10]
(FASER Collaboration)



LOCATION, LOCATION, LOCATION

FASER
Pilot Detector

Suitcase-size
4 Weeks
$0 (recycled parts)

6 ν candidates

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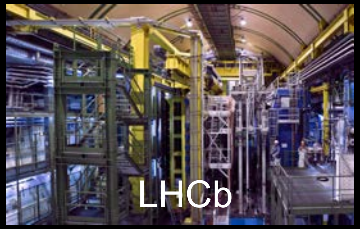

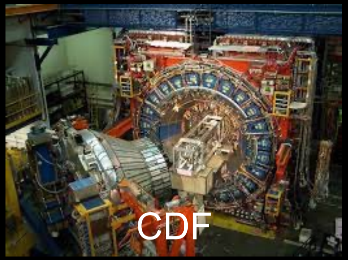

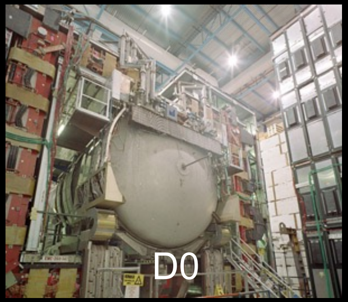

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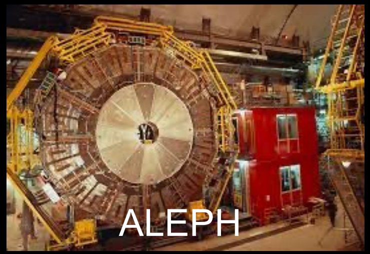
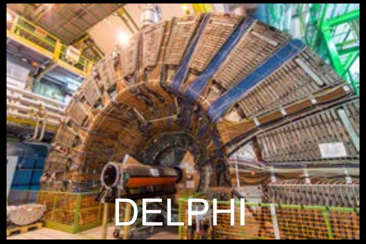
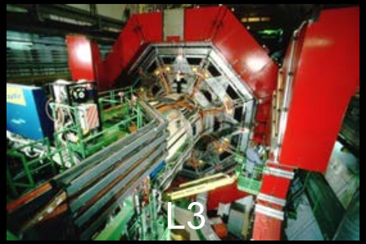
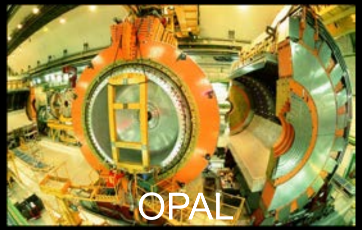








All Previous
Collider Detectors

Building-size
Decades
$billions

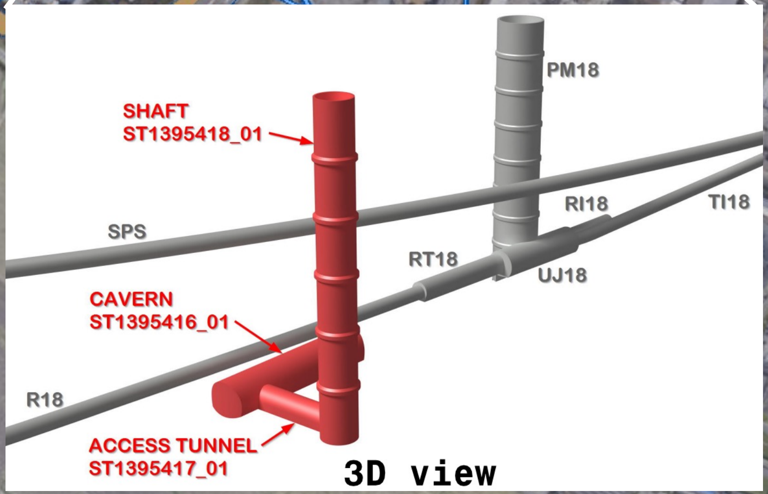
0 ν candidates

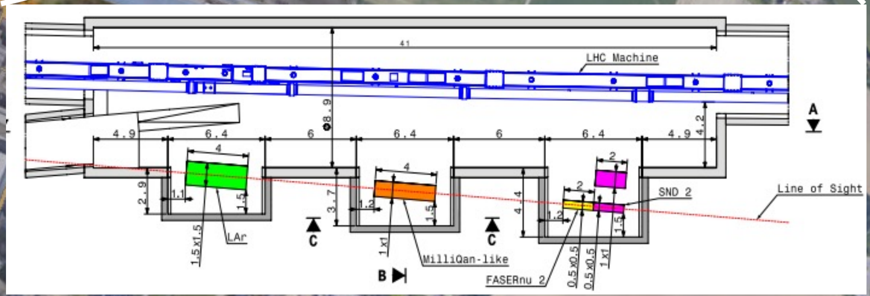
FORWARD PHYSICS FACIILITY

Possibilities under active investigation:

(1) enlarge existing cavern UJ12 with alcoves for each experiment

(2) create a new shaft and cavern ~612 m from ATLAS past UJ18





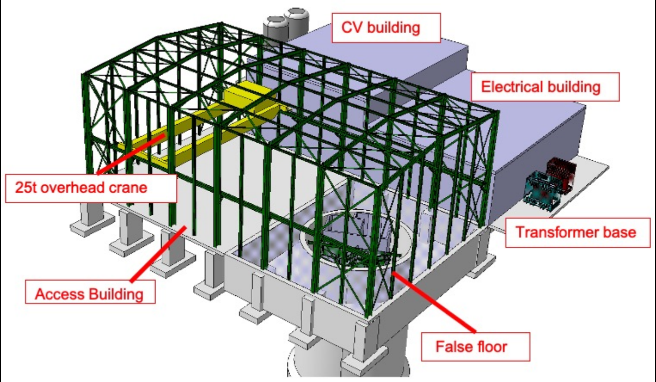
John Osborne, Kincso Balazs, Jonathan Gall

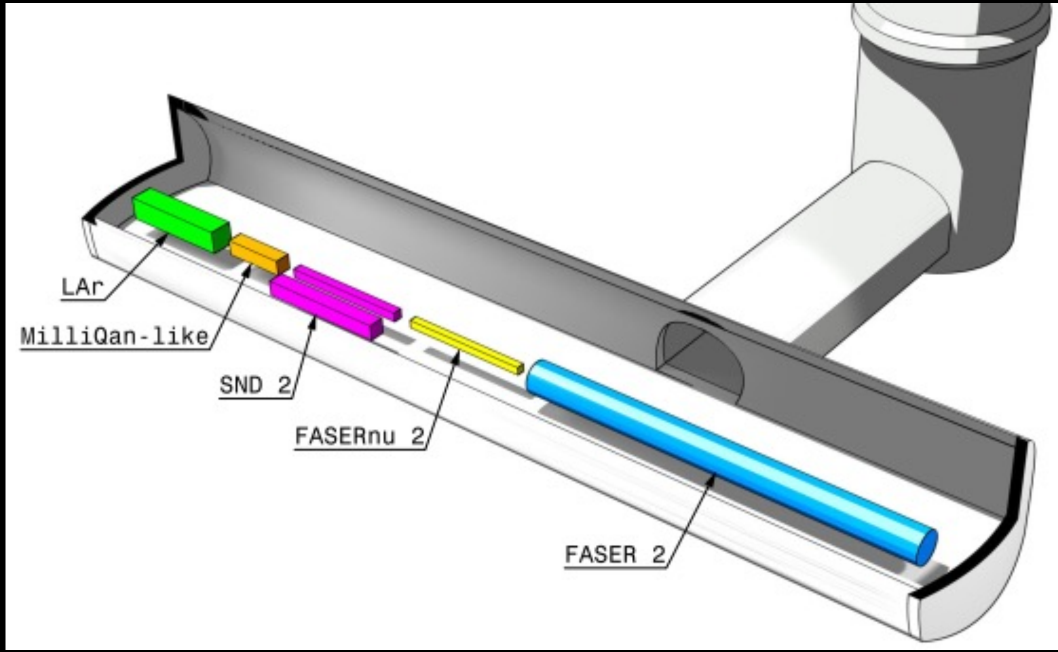
see John Osborne's talk, PBC Workshop 3/3/21

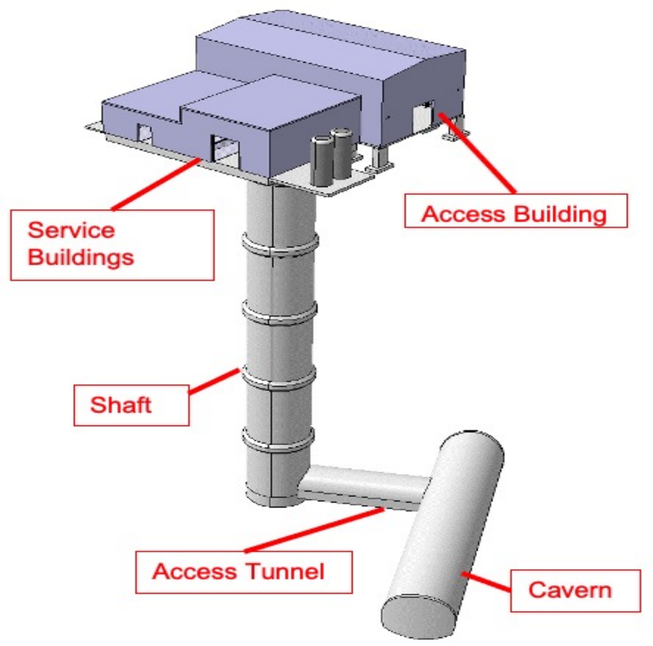
CERN GIS

NEW SHAFT AND CAVERN

- Many advantages
  - Construction access far easier
  - Access possible during LHC operations
  - Flexible size and length of cavern (> 60 m)
  - Designed around needs of the experiments







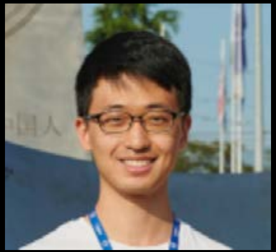
Design by Liam Dougherty (EN-ACE-INT)

FASER AND FORWARD PHYSICS AT UCI

UNDERGRADS


Alan Barkley-Yeung


Ryan Rice-Smith


Kyungseop Yoon

GRADUATE STUDENTS


Jason Arakawa


Tyler Smith


Max Fieg


Jordan Smolinsky


Johanna Paine

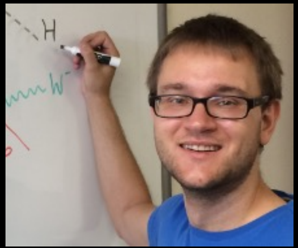

Aaron Soffa


Savannah Shively


Michael Waterbury

POSTDOCS


Iftah Galon


Felix Kling


Sebastian Trojanowski


Mauro Valli

STAFF


Alison Lara


Grace Park


Shelley Scallan


Chris Sepulveda

FACULTY


Dave Casper


Jonathan Feng


Tim Tait

SUPPORTERS

UC IRVINE

HEISING-SIMONS FOUNDATION

SIMONS FOUNDATION

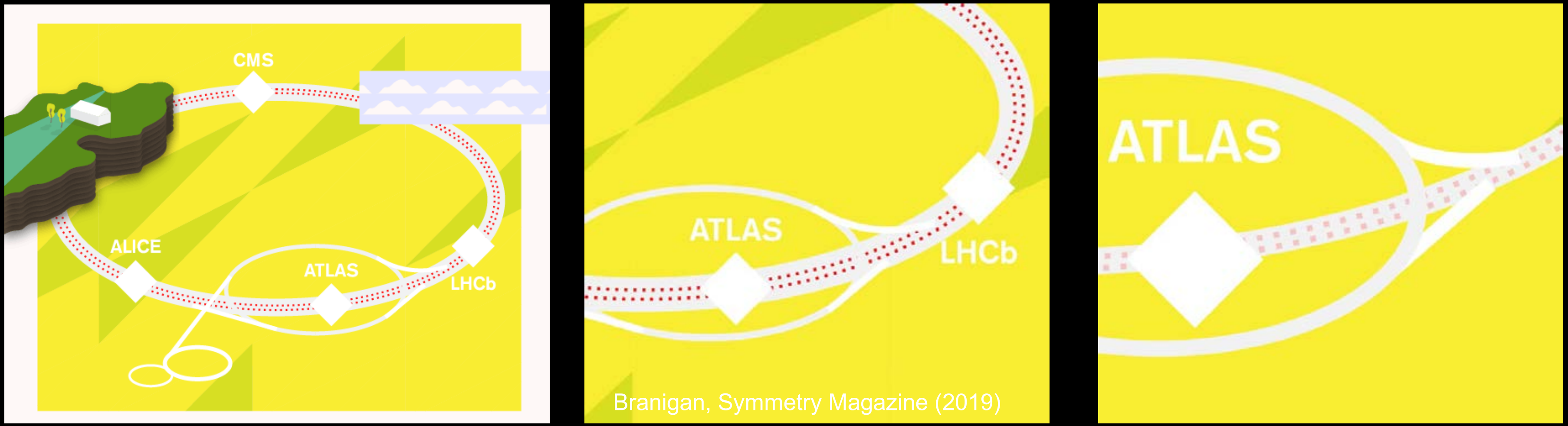
NSF

CERN

Corwin and Nancy Evans

CONCLUSIONS

- 95% of the universe is waiting to be discovered.
- Relatively small, fast, and cheap experiments can provide world-leading searches.
- FASER was proposed in 2017, funded in 2018, approved in 2019, constructed in 2020, installed in 2021. In 2022, when the LHC turns on again, we will detect ~10,000 collider neutrinos, and, perhaps, get our first glimpse of the dark universe.



Branigan, Symmetry Magazine (2019)

https://faser.web.cern.ch