FASTER, SMALLER, CHEAPER

FORWARD SEARCH EXPERIMENT AT THE LHC

Department Colloquium, UC Irvine

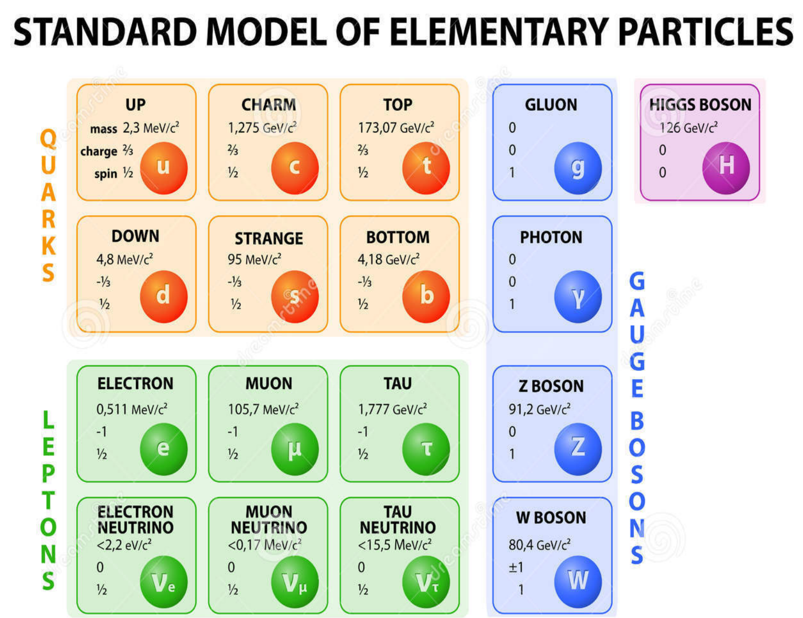
Jonathan Feng, UC Irvine, 25 April 2019

HEISING-SIMONS FOUNDATION

SIMONS FOUNDATION

THE STATE OF PARTICLE PHYSICS

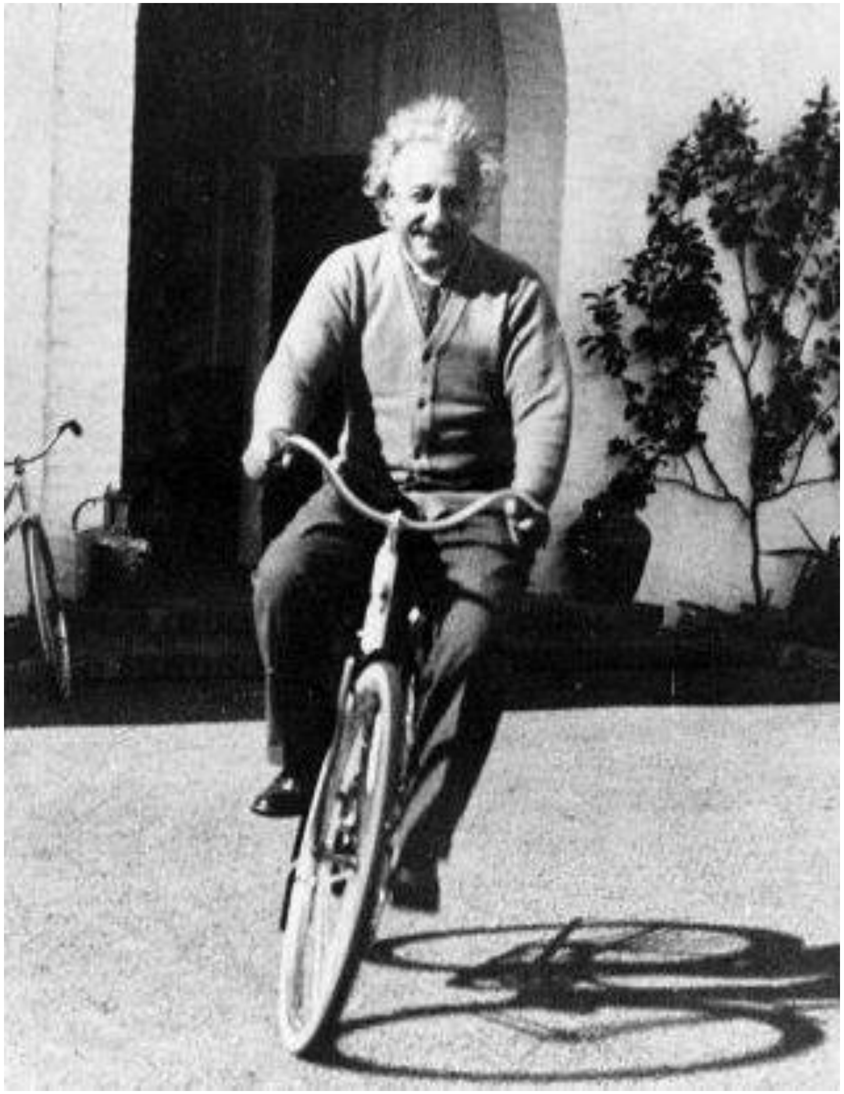
- In the last century, we have been tremendously successful in discovering new particles and deepening our understanding of the laws of nature and the contents of the Universe.



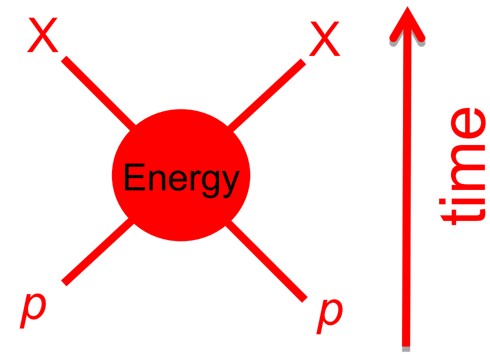
- The workhorse tool leading to many of these discoveries has been the particle collider.

- Particle collider experiments started small, but are now quintessentially “big science.” This evolution can be understood as the legacy of two giants of physics: Albert Einstein and Ernest O. Lawrence.

ALBERT EINSTEIN



- In 1905 Einstein discovered $E = mc^2$:
- This allows the process



- Energy is the "universal translator": we can collide known particles with high energy, which transforms into the mass of new particles.
- We can therefore discover new particles, even if we don't know exactly what we are looking for.

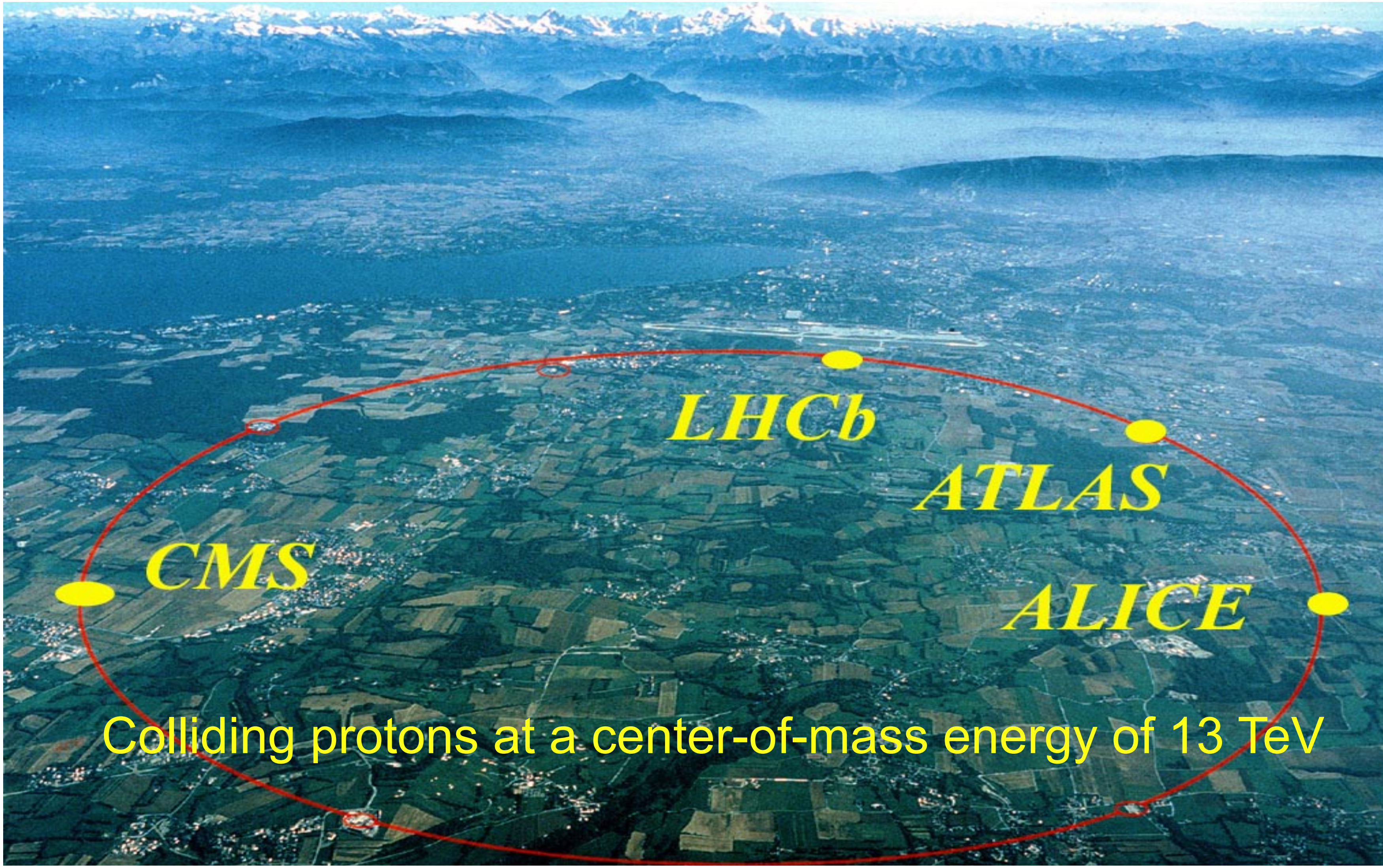
ERNEST O. LAWRENCE

- In the 1930's Lawrence made a cyclotron, which accelerated particles to higher velocities and energies.

- The first cyclotron was small, but soon, bigger accelerators led to higher energies, which allowed heavier particles to be produced and discovered.

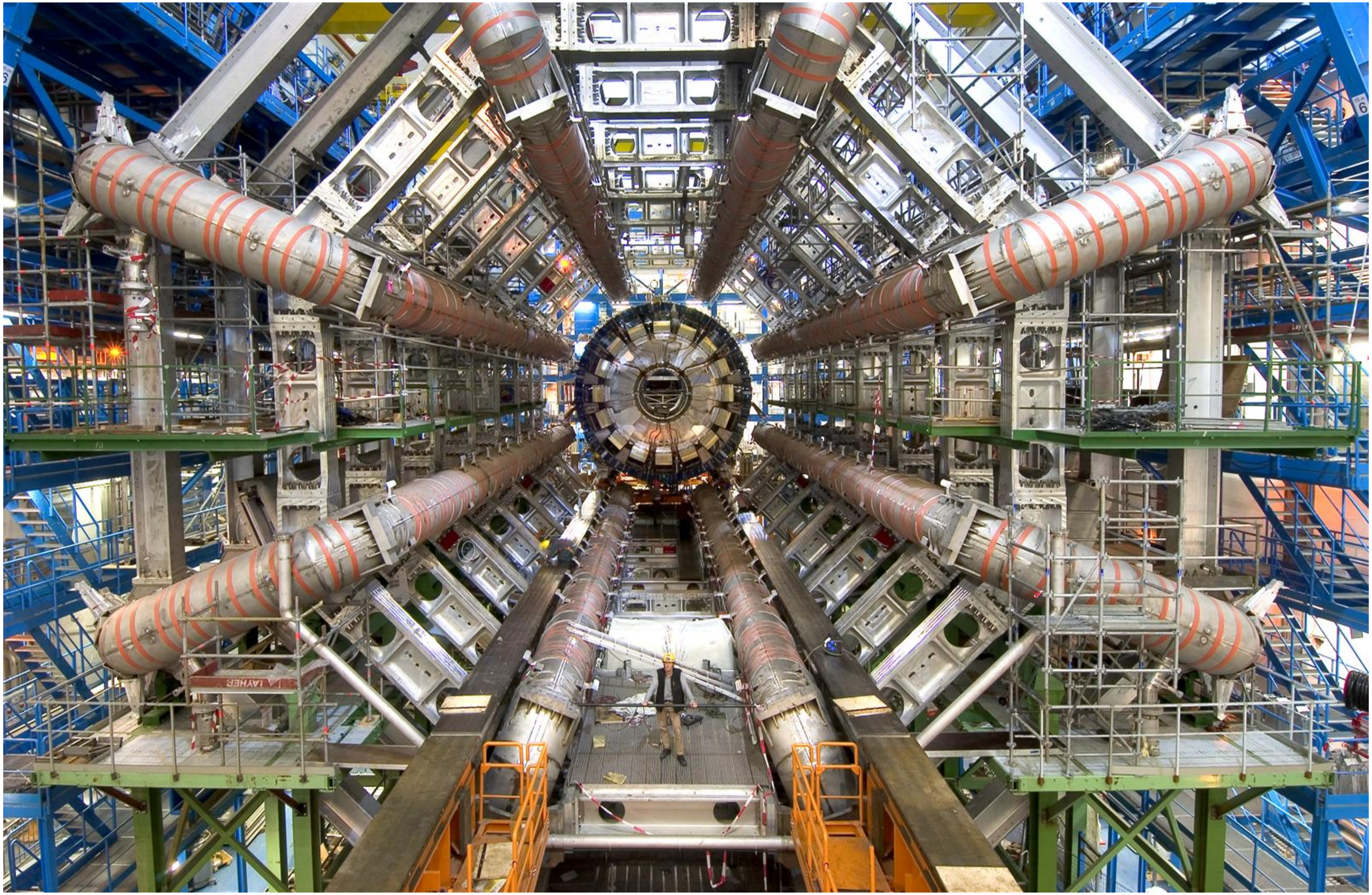
THE LARGE HADRON COLLIDER

The latest realization of Lawrence's vision: the LHC in Geneva



THE ATLAS DETECTOR

One of several giant detectors that observe particle collisions at the LHC



HOW BIG IS BIG SCIENCE?

- Size: Big.
- Timescale: The LHC was conceived in the 1980's. It was constructed from 1998-2008, and has been running since 2008, with periodic shutdowns to upgrade and fix equipment.
- Budget: The cost of constructing the LHC and the various experiments was roughly $10 billion. The annual operations budget of CERN, the host laboratory, is about $1 billion/year, or roughly 1 coffee per year per EU citizen.
- People: Many.

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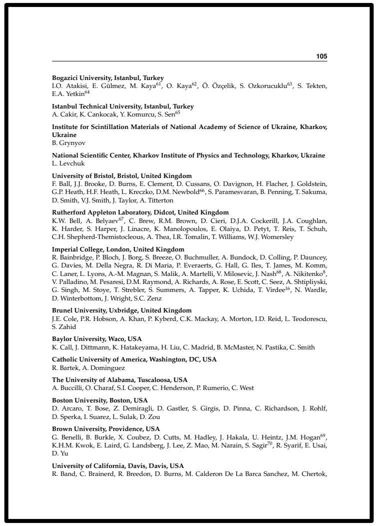
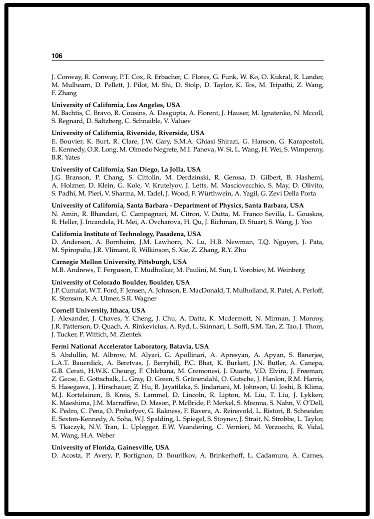
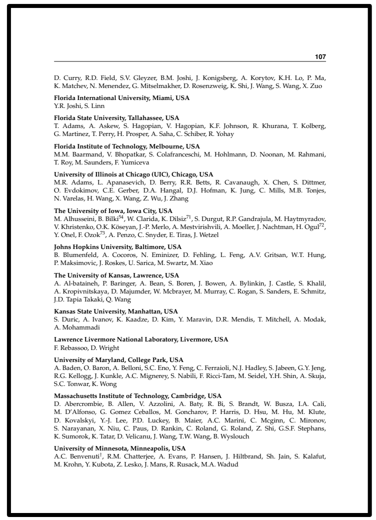
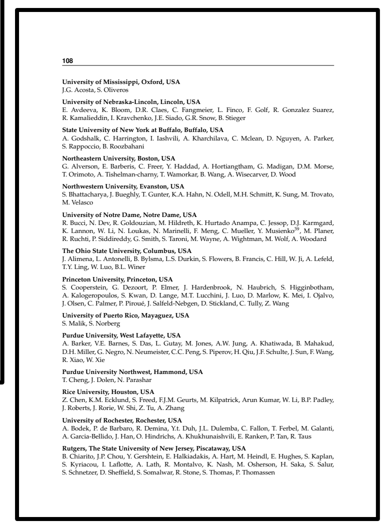
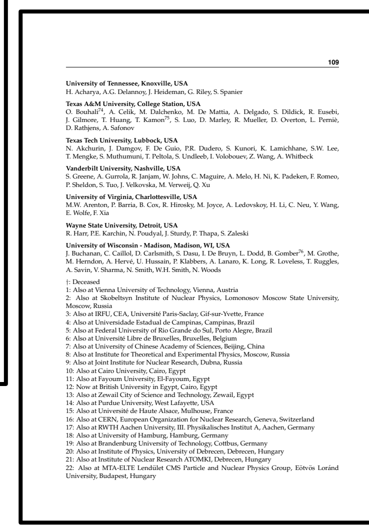








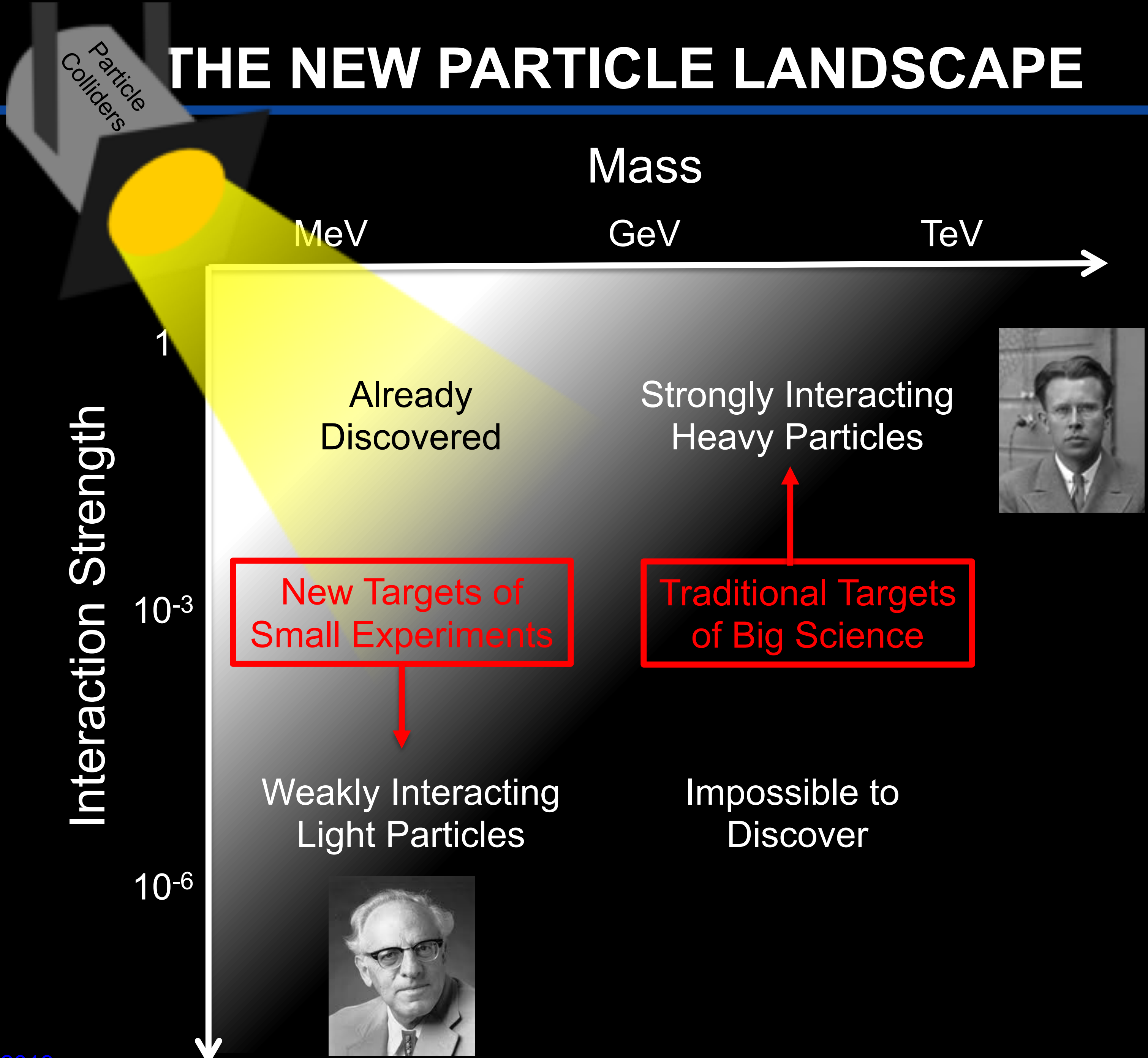


4000 collaborators from 230 institutions in 51 countries

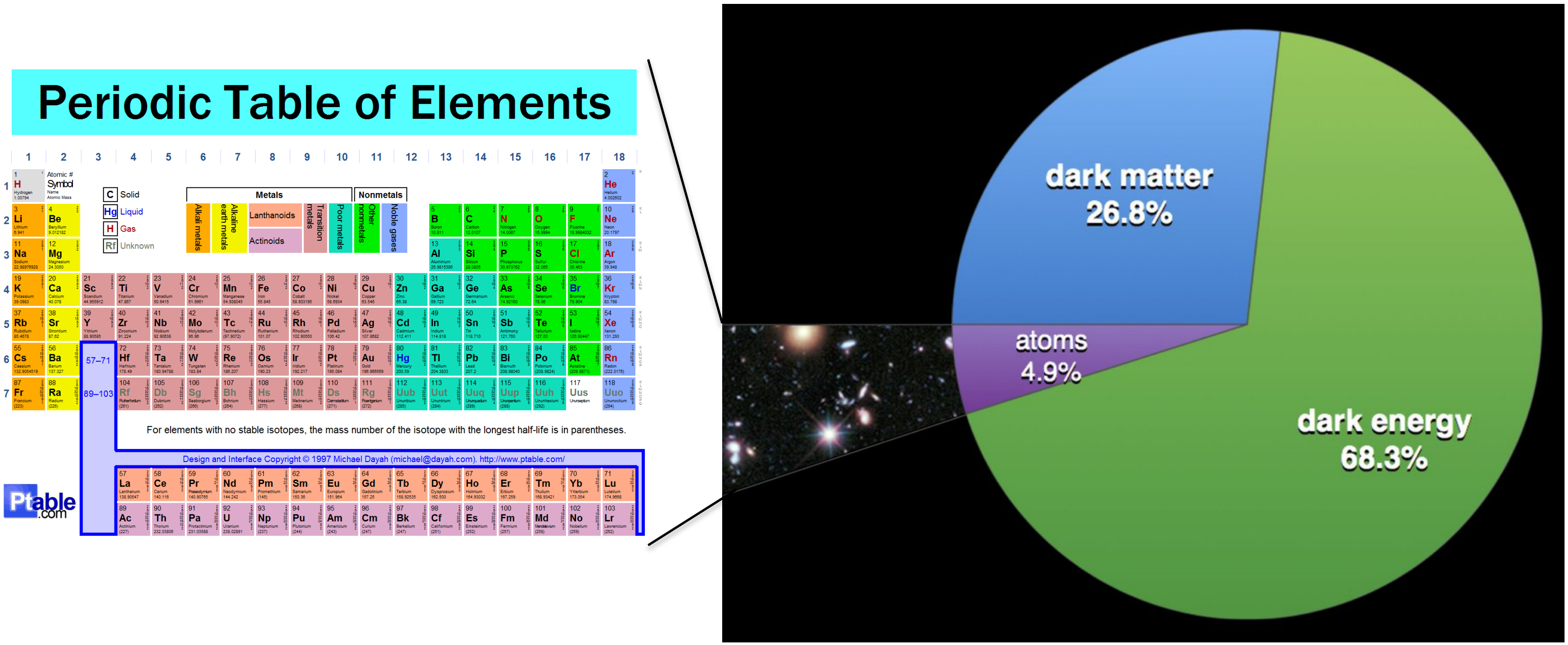
PARTICLE PHYSICS: CURRENT STATUS

- The discovery of the Higgs boson in 2012 was an amazing achievement that completed the standard model of particle physics.
- But after the Higgs boson, there has been no evidence for new particles.
- The LHC is currently in Long Shutdown 2, but will start up again in 2021 and run for another ~15 years.
- What other approaches can enhance the prospects for discovering new particles?

THE NEW PARTICLE LANDSCAPE



THE UNIVERSE TODAY



- We now have an overall picture of the Universe
- We know a lot about a little: the normal matter (5%)
- But we know little about a lot: dark matter / dark energy (95%). Most of the universe is still to be discovered and understood.

DARK MATTER

- What properties should DM have?

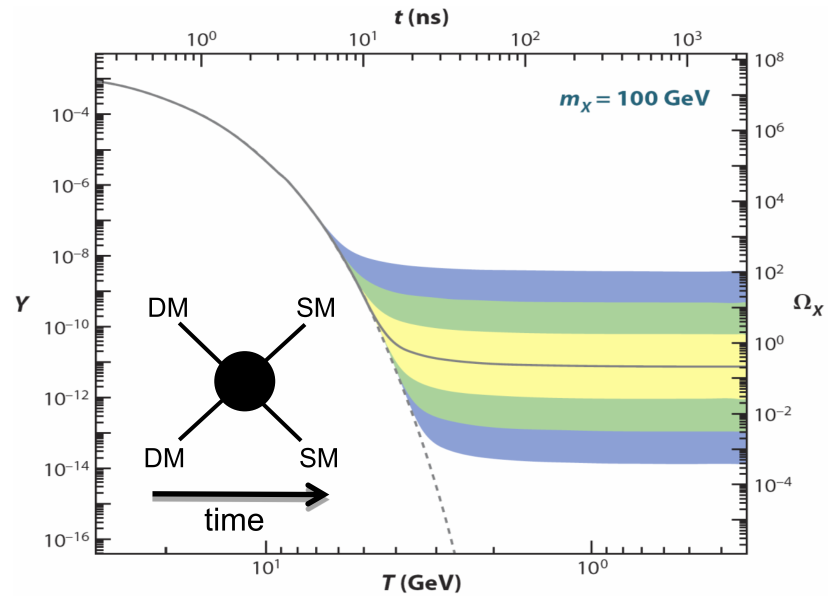
- A simple mechanism for generating DM: in the early universe, DM particles annihilate in pairs until they "freeze out."

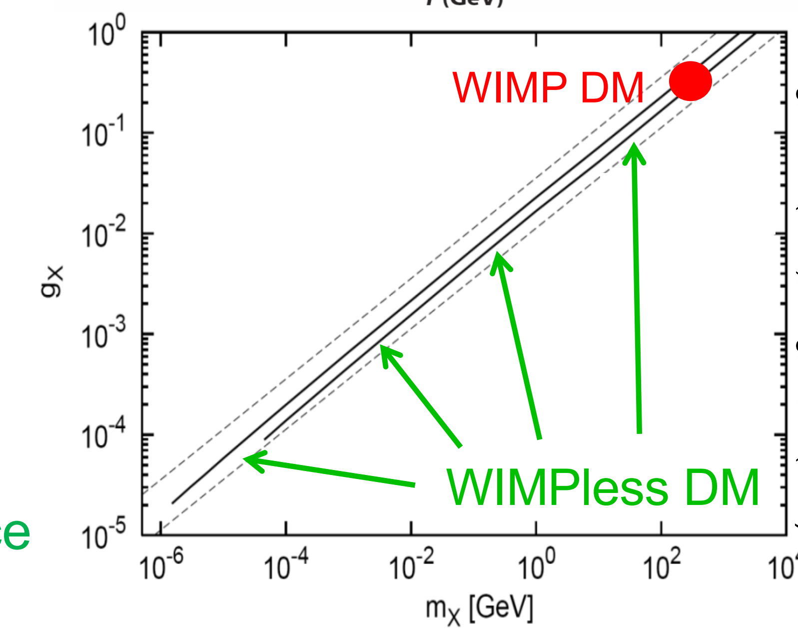
- The weaker their interactions, the more dark matter survives to the present day:

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

- WIMP Miracle: ~100 GeV to 1 TeV masses, strong couplings → right abundance

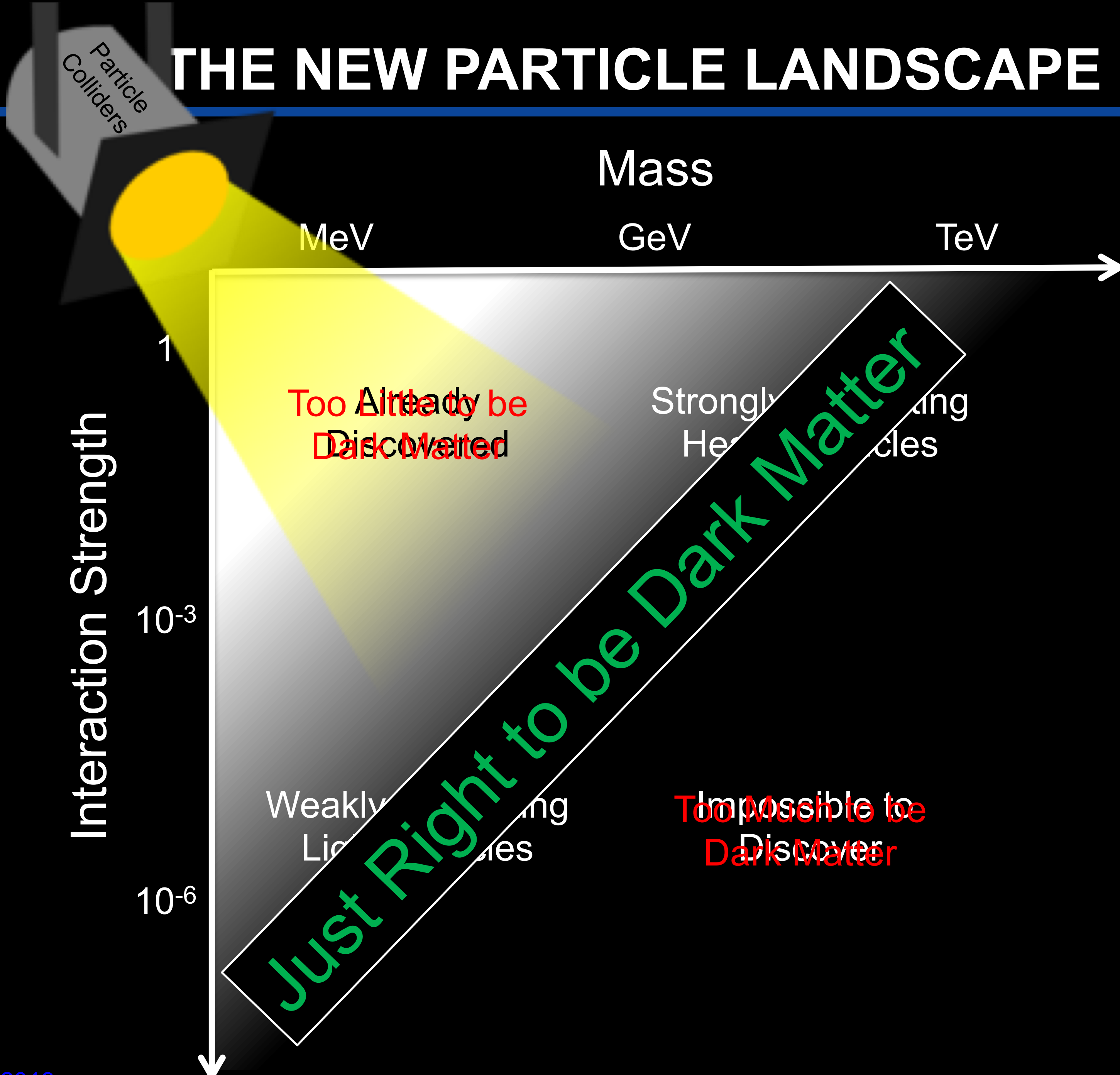
- WIMPless Miracle: lighter particles, weaker interactions → right abundance





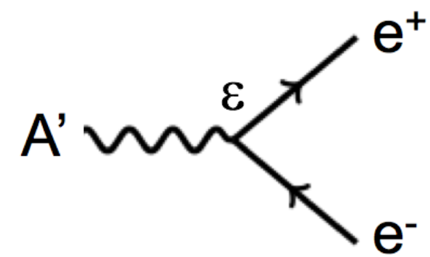
Feng, Kumar (2008); Feng, Tu, Yu (2010)

THE NEW PARTICLE LANDSCAPE



THE LIFETIME FRONTIER

- How can we look for light and weakly interacting particles? Consider a neutral particle with energy E ~ TeV, mass m ~ 100 MeV, coupling $\varepsilon \sim 10^{-5}$.
- They pass through matter essentially without interacting: radiation length is (10 cm) $\varepsilon^{-2} \sim 10^9$ m. The distance to the moon!
- They may decay to visible particles, but only after traveling a long distance.



Velocity near the speed of light

$$v \approx 1$$

Rest lifetime enhanced by small mass, small ε

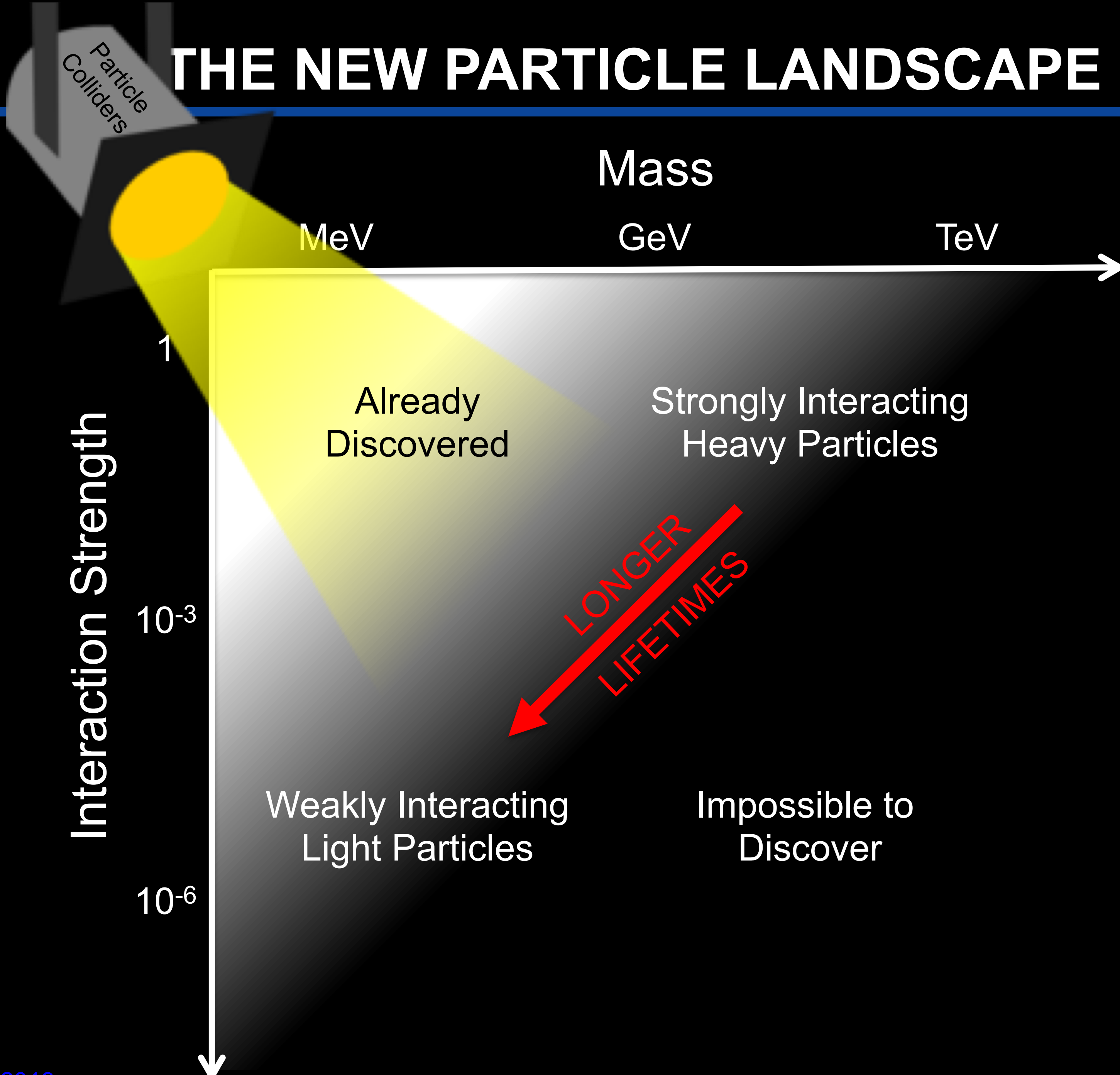
$$\tau \propto \frac{1}{\epsilon^2 m}$$

Lifetime further enhanced by time dilation

$$\gamma \propto \frac{E}{m}$$

$$L = v\tau\gamma \sim (100\text{ m}) \left[\frac{10^{-5}}{\epsilon}\right]^2 \left[\frac{100\text{ MeV}}{m}\right]^2 \left[\frac{E}{\text{TeV}}\right]$$

THE NEW PARTICLE LANDSCAPE



LOTS OF ACTIVITY

Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

1903.04497

March 6, 2019

Particles beyond the Standard Model (SM) can generically have lifetimes that are long compared to SM particles at the weak scale. When produced at experiments such as the Large Hadron Collider (LHC) at CERN, these long-lived particles (LLPs) can decay far from the interaction vertex of the primary proton-proton collision. Such LLP signatures are distinct from those of promptly decaying particles that are targeted by the majority of searches for new physics at the LHC, often requiring customized techniques to identify, for example, significantly displaced decay vertices, tracks with atypical properties, and short track segments. Given their non-standard nature, a comprehensive overview of LLP signatures at the LHC is beneficial to ensure that possible avenues of the discovery of new physics are not overlooked. Here we report on the joint work of a community of theorists and experimentalists with the ATLAS, CMS, and LHCb experiments — as well as those working on dedicated experiments such as MoEDAL, milliQan, MATHUSLA, CODEX-b, and FASER — to survey the current state of LLP searches at the LHC, and to chart a path for the development of LLP searches into the future, both in the upcoming Run 3 and at the High-Luminosity LHC. The work is organized around the current and future potential capabilities of LHC experiments to generally discover new LLPs, and takes a signature-based approach to surveying classes of models that give rise to LLPs rather than emphasizing any particular theory motivation. We develop a set of simplified models; assess the coverage of current searches; document known, often unexpected backgrounds; explore the capabilities of proposed detector upgrades; provide recommendations for the presentation of search results; and look towards the newest frontiers, namely high-multiplicity "dark showers", highlighting opportunities for expanding the LHC reach for these signals.

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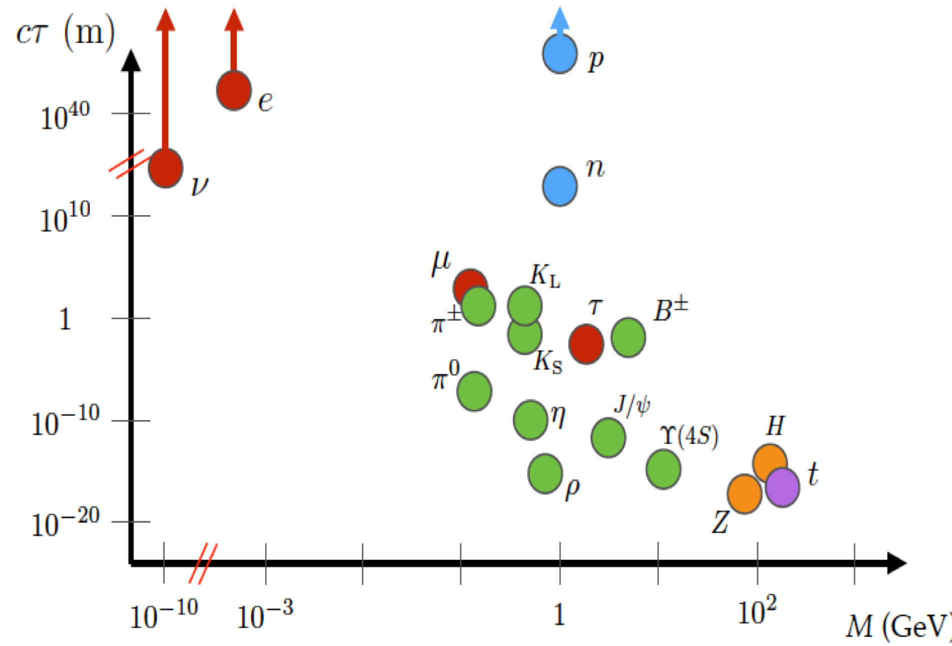
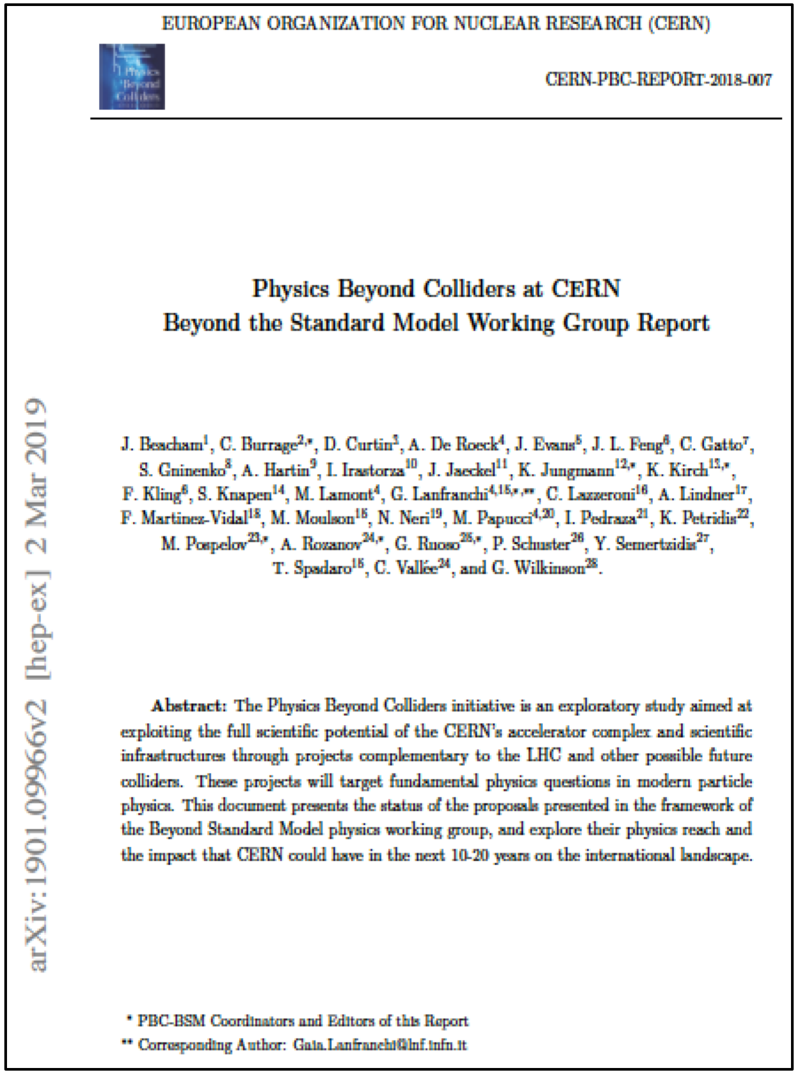


Figure 1.1: Particle lifetime $c\tau$, expressed in meters, as a function of particle mass, expressed in GeV, for a variety of particles in the Standard Model [1].

LOTS OF ACTIVITY



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PBC-REPORT-2018-007

Physics Beyond Colliders at CERN
Beyond the Standard Model Working Group Report

J. Beacham[1], C. Burrage[2,*], D. Curtin[3], A. De Roeck[4], J. Evans[5], J. L. Feng[6], C. Gatto[7], S. Gninenko[8], A. Hartin[9], I. Irastorza[10], J. Jaeckel[11], K. Jungmann[12,*], K. Kirch[13,*], F. Kling[6], S. Knapen[14], M. Lamont[4], G. Lanfranchi[4,15,*,**], C. Lazzeroni[16], A. Lindner[17], F. Martinez-Vidal[18], M. Moulson[15], N. Neri[19], M. Papucci[4,20], I. Pedraza[21], K. Petridis[22], M. Pospelov[23,*], A. Rozanov[24,*], G. Ruoso[25,*], P. Schuster[26], Y. Semertzidis[27], T. Spadaro[15], C. Vallée[24], and G. Wilkinson[28].

Abstract: The Physics Beyond Colliders initiative is an exploratory study aimed at exploiting the full scientific potential of the CERN's accelerator complex and scientific infrastructures through projects complementary to the LHC and other possible future colliders. These projects will target fundamental physics questions in modern particle physics. This document presents the status of the proposals presented in the framework of the Beyond Standard Model physics working group, and explore their physics reach and the impact that CERN could have in the next 10-20 years on the international landscape.

* PBC-BSM Coordinators and Editors of this Report
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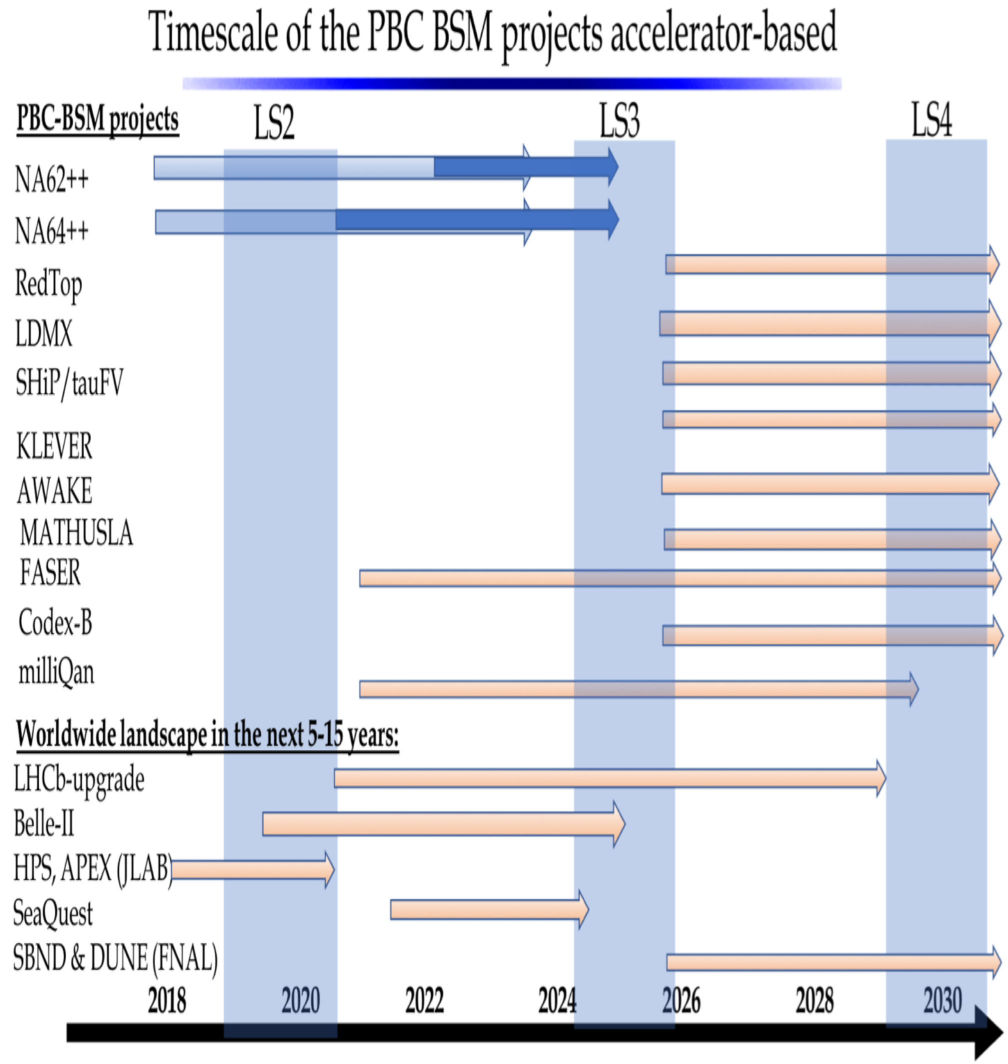
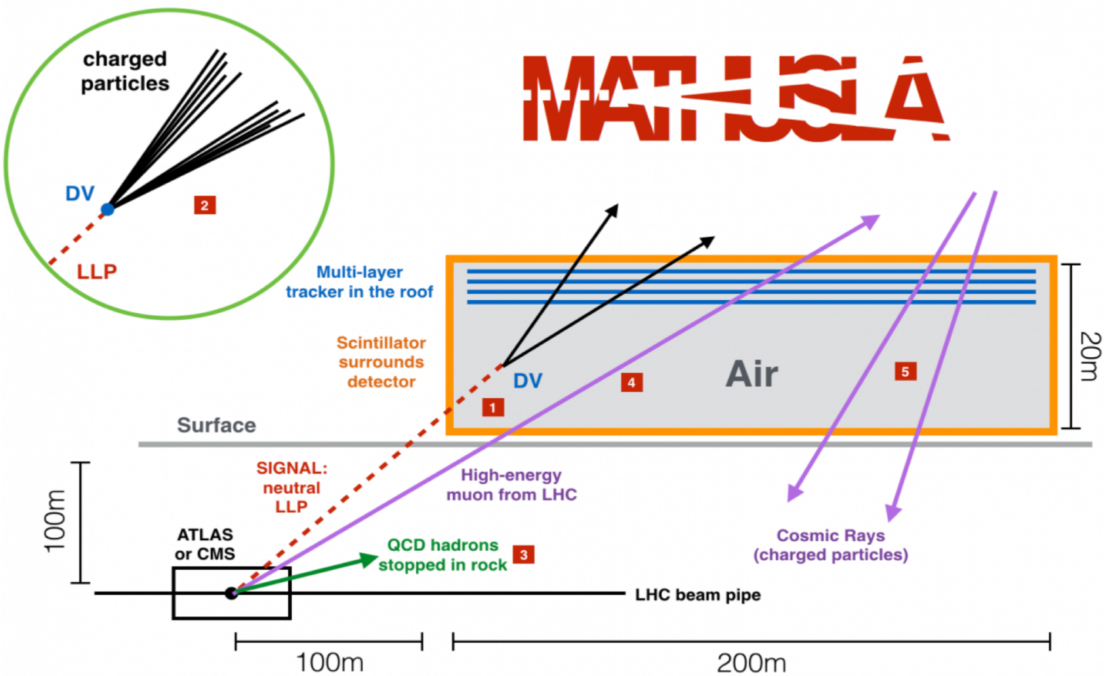


MATHUSLA

- Long-lived particles (LLPs) can escape from current LHC detectors, motivate detectors placed further away, where backgrounds are low.
- MATHUSLA, MAssive Timing Hodoscope for Ultra-Stable neutral pArticles, is a proposed surface detector.

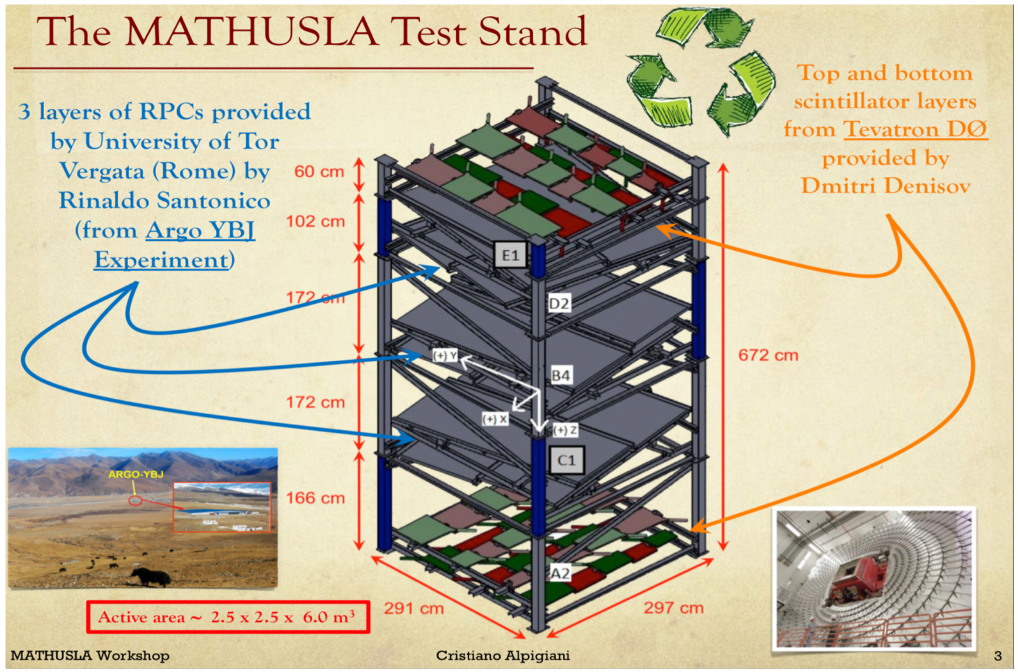
Chou, Curtin, Lubatti (2016)

- Ideal target is LLPs produced in the decays of heavy particles: for example, h → (LLP)(LLP) → e^+e^- e^+e^-.



MATHUSLA STATUS

- Data already taken in 2018 to evaluate collider and cosmic ray backgrounds with LHC on and off, respectively.



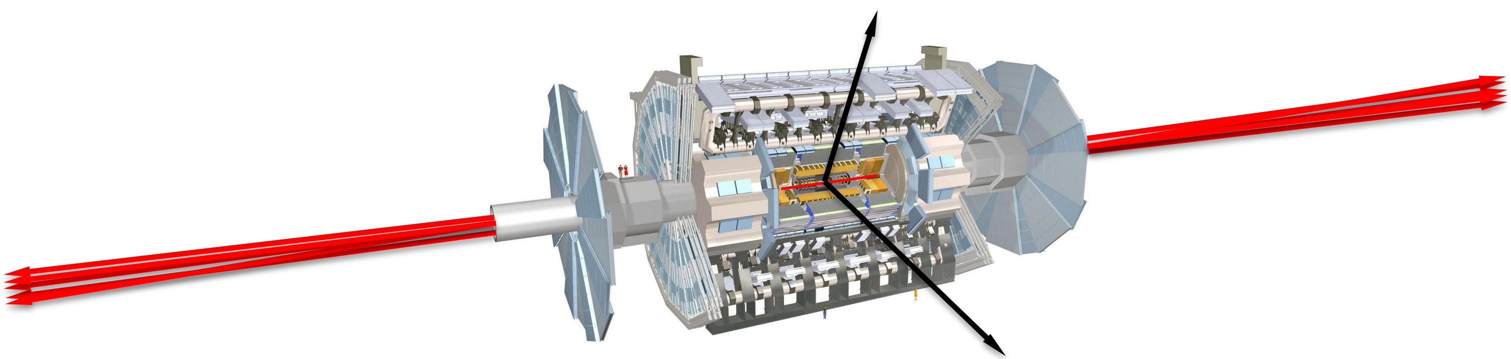
- Cost: ~ several x $10,000,000

- Letter of Intent submitted to CERN in July 2018, recommended for evaluation in the European Strategy for Particle Physics exercise (2020).

FASER

- If new particles are light and weakly interacting, they can also be produced in the decays of light particles
  - Light → they may be produced in π, *K*, *D*, *B* decays…
  - Weakly-interacting → …but extremely rarely in π, *K*, *D*, *B* decays

- More promising to go where the π, *K*, *D*, *B* particles are: along the beamline.
  - For example, the LHC produces ~10^{16} pions per year
  - But for E > 10 GeV, 10% of these (and most of the high energy ones) are produced within 2 mrad of the beamline.



FASER

- 2 mrad is very small ($\eta > 7$)
  - Moon diameter is 9 mrad.
  - The ATLAS and CMS detectors have holes here to let the proton beams in and so are completely blind to these particles.

- Can we cover this “blind spot”? A detector on the beamline would block the proton beams. However, our target particles do not interact, so travel straight, and are also long-lived. We can therefore place the detector on the “line of sight,” a few 100 m away, after the beam curves.

- (100 m) (mrad) = 10 cm → particles are still highly collimated.

- These considerations motivate a small, inexpensive experiment placed in the very forward region of ATLAS/CMS, a few 100m downstream.

Feng, Galon, Kling, Trojanowski (2017)

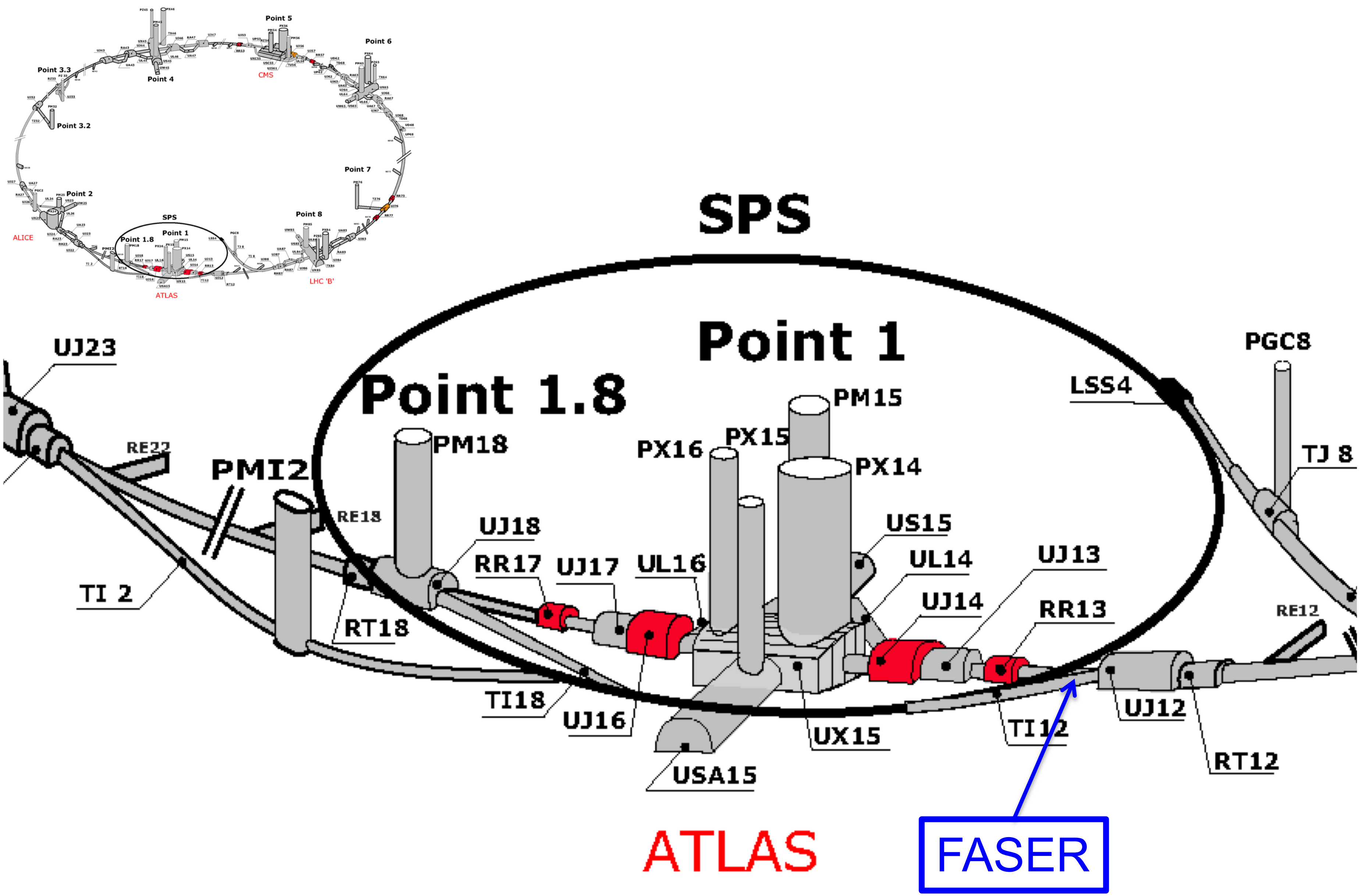
FORWARD SEARCH EXPERIMENT

FASER

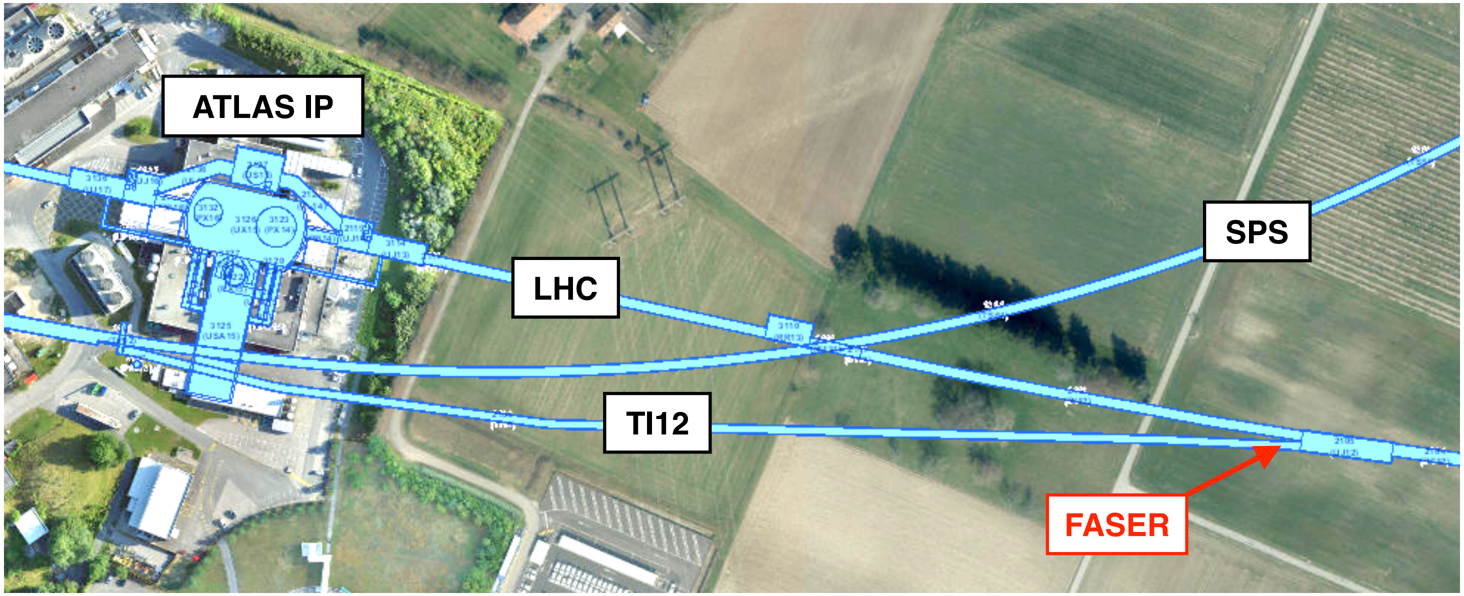
- “The acronym recalls another marvelous instrument that harnessed highly collimated particles and was used to explore strange new worlds.”

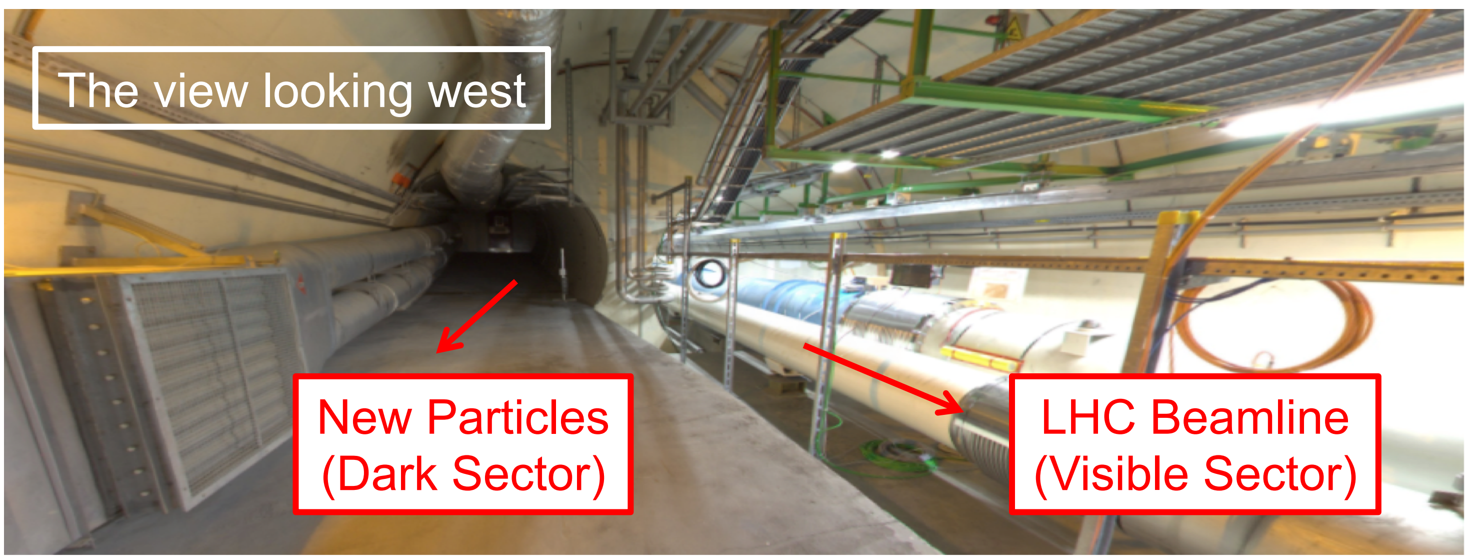
  Feng, Galon, Kling, Trojanowski (2017)

FASER LOCATION



FASER LOCATION





FASER LOCATION

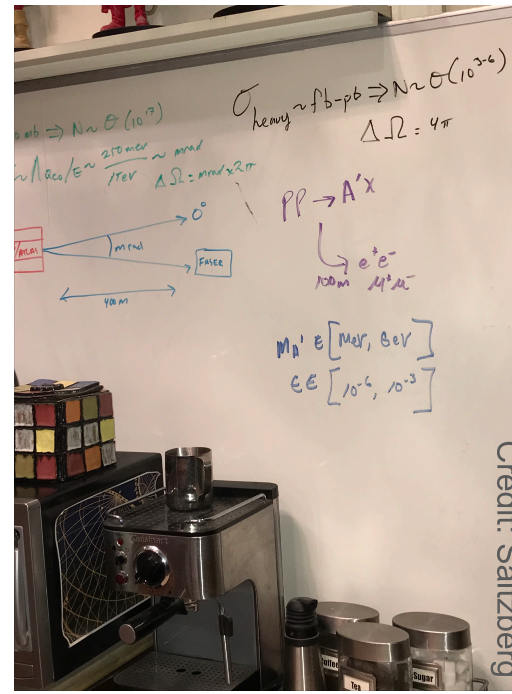
Dougherty, CERN Integration (2019)

FASER TIMELINE

- September 2017: First theory paper
- November 2017: Support from the two most famous living physicists
- July 2018: Submitted LOI to CERN LHCC
- October 2018: Approval from ATLAS SCT and LHCb Collaborations for use of spare detector modules
- November 2018: Submitted Technical Proposal to LHCC
- November – December 2018: Construction fully funded by 2 $1M grants from the Heising-Simons and Simons Foundations
- March 2019: FASER fully approved by CERN along with support for infrastructure costs
- April 2019: 1st FASER Collaboration Meeting
- 2019-21: Install FASER in Long Shutdown 2
- 2021-23: Collect data in Run 3 with the potential to discover new elementary particles and new fundamental forces

FASER

- Support from the two most famous living physicists



Credit: Saltzberg

Season 11, Episode 9, “The Bitcoin Entanglement” (November 2017)

FASER COLLABORATION

- The FASER Collaboration: 37 collaborators, 16 institutions, 8 countries

Claire Antel (Geneva), Akitaka Ariga (Bern), Tomoko Ariga (Kyushu/Bern), Jamie Boyd* (CERN), Dave Casper (UC Irvine), Franck Cadoux (Geneva), Xin Chen (Tsinghua), Andrea Coccaro (INFN), Candan Dozen (Tsinghua), Yannick Favre (Geneva), Jonathan Feng* (UC Irvine), Didier Ferrere (Geneva), Iftah Galon (Rutgers), Sergio Gonzalez-Sevilla (Geneva), Shih-Chieh Hsu (Washington), Zhen Hu (Tsinghua), Peppe Iacobucci (Geneva), Sune Jakobsen (CERN), Roland Jansky (Geneva), Enrique Kajomovitz (Technion), Felix Kling (UC Irvine), Susanne Kuehn (CERN), Lorne Levinson (Weizmann), Josh McFayden (CERN), Friedemann Neuhaus (Mainz), Hidetoshi Otono (Kyushu), Lorenzo Paolozzi (Geneva), Brian Petersen (CERN), Osamu Sato (Nagoya), Matthias Schott (Mainz), Anna Sfyrla (Geneva), Jordan Smolinsky (UC Irvine), Aaron Soffa (UC Irvine), Yosuke Takubo (KEK), Eric Torrence (Oregon), Sebastian Trojanowski (Sheffield), Gang Zhang (Tsinghua)

FIRST FASER COLLABORATION MEETING

ACKNOWLEDGEMENTS

The FASER Collaboration has also received essential support from many others

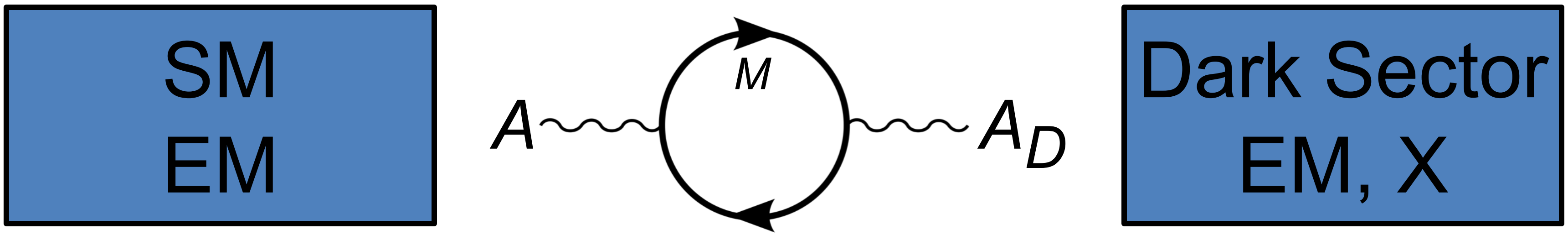
We are grateful to the ATLAS SCT project and the LHCb Calorimeter project for letting us use spare modules as part of the FASER experiment. In addition, FASER acknowledges the invaluable assistance from the CERN Physics Beyond Colliders study group; the LHC Tunnel Region Experiment (TREX) working group; the LHC Machine Committee; the LS2 Committee and the LHCC. FASER gratefully acknowledges the contributions from:

- Jonathan Gall, John Osborne (civil engineering);
- Liam Dougherty, Francisco Galan (integration);
- Pierre Thonet (magnets);
- Francesco Cerutti, Marta Sabate Gilarte (FLUKA simulation and background characterization);
- Salvatore Danzeca, Serge Chalaye (radiation measurements);
- James Storey, Swann Levasseur (beam instrumentation);
- Pierre Valentin, Tobias Dobers (survey);
- Caterina Bertone, Serge Pelletier, Frederic Delsaux (transport);
- Gael Girardot, Olivier Crespo-Lopez, Yann Maurer, Maria Papamichali (LS2 works);
- Marzia Bernardini, Anne-Laure Perrot, Katy Foraz, Markus Brugger (LHC access and schedule);
- Marco Andreini, Olga Beltramello, Thomas Otto (safety);
- Dave Robinson (ATLAS SCT), Yuri Guz (LHCb calorimeters);
- Stephen Wotton, Floris Keizer (SCT QA system and SCT readout);
- Burkhard Schmitt, Raphael Dumps, Sune Jacobsen, Giovanna Lehmann (CERN-DT contributions);
- Mike Lamont, Andreas Hoecker, Ludovico Pontecorvo, Christoph Rembser (useful discussions).

Thanks also to the CERN management for their support!

AN EXAMPLE: DARK PHOTONS

- Suppose there is a dark sector that contains dark matter X and also a dark force: dark electromagnetism.
- Generically, the force carriers of the SM and dark EMs will mix



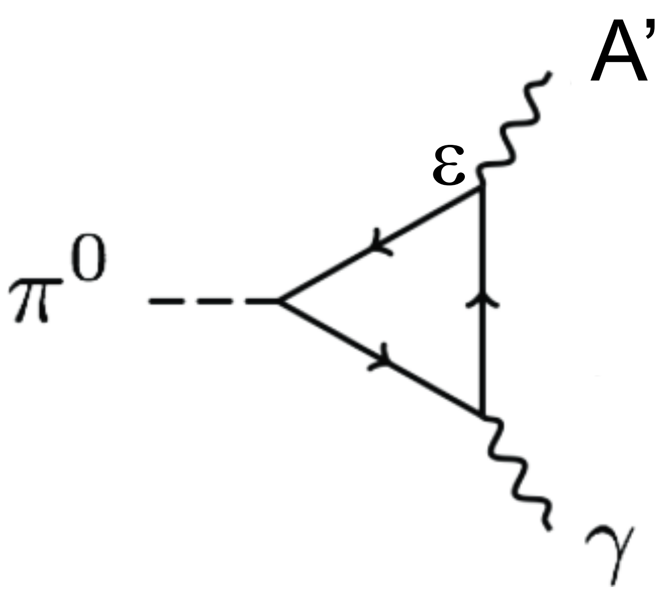
- The resulting theory contains a new gauge boson, the dark photon A', with mass $m_{A'}$ and εQ_f couplings to SM fermions f, where ε is loop-induced and so expected to be small.

Okun (1982), Galison, Manohar (1984), Holdom (1986)

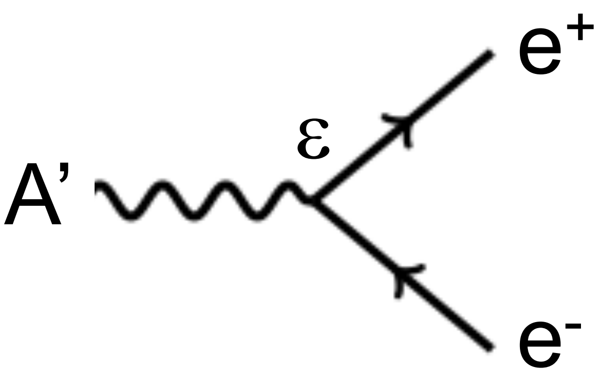
FASER PHYSICS: DARK PHOTONS

- The dark photon is like the standard photon, but
  - It is massive, with a mass $m_{A'}$
  - Its coupling to SM particles is suppressed by a small coupling ε

- It can be produced, for example, in pion decay:

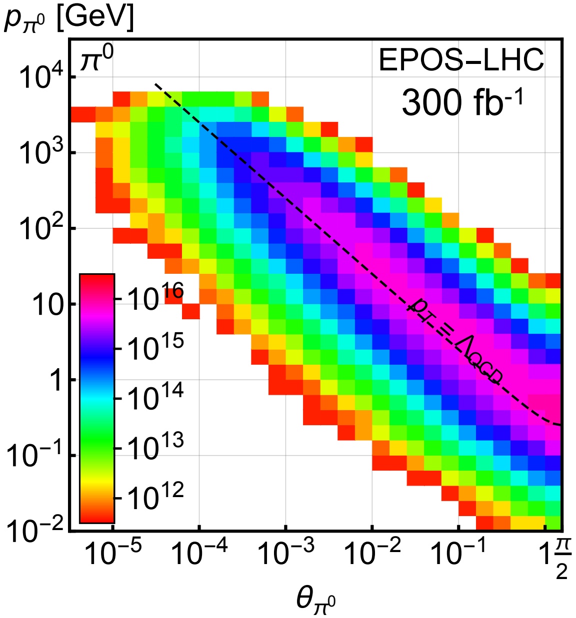


- It can decay to particle/anti-particle pairs:

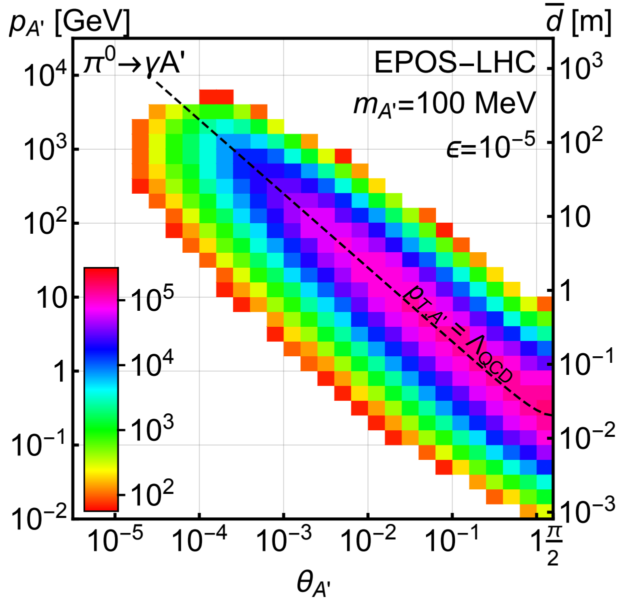


SIGNALS: DARK PHOTONS

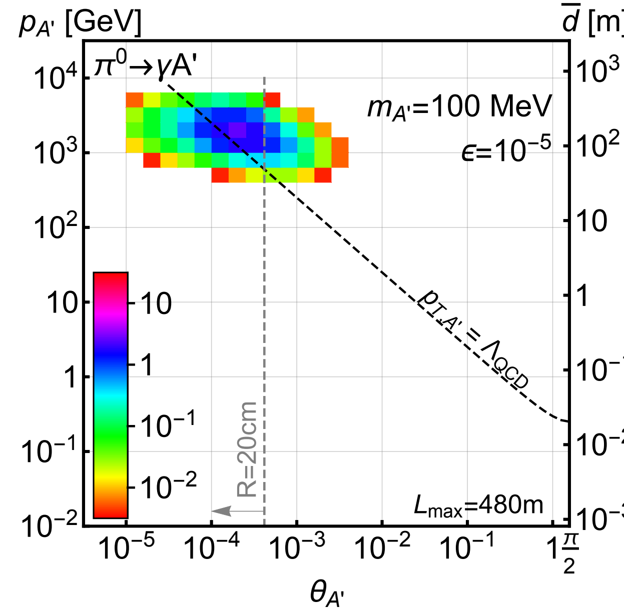
Pions at the IP



A's at the IP



A's decay in FASER

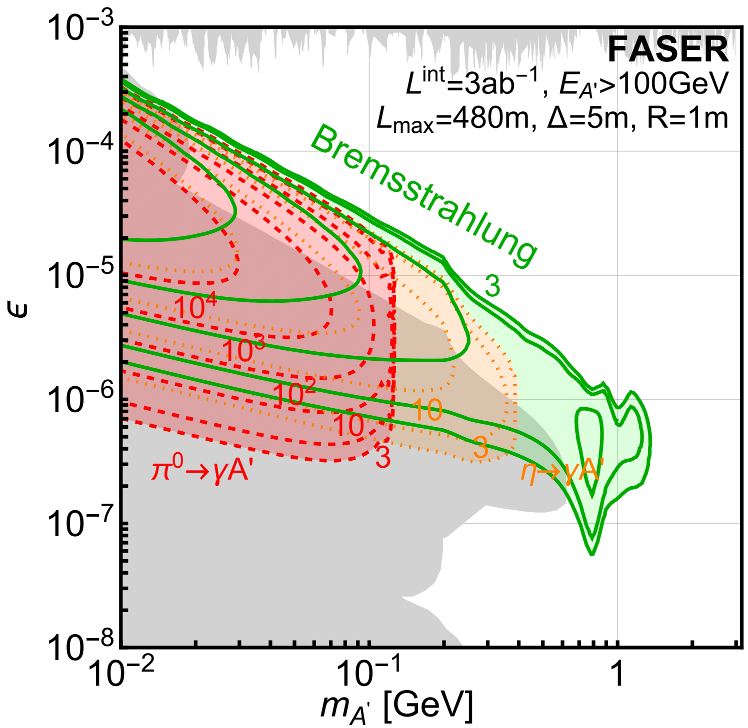


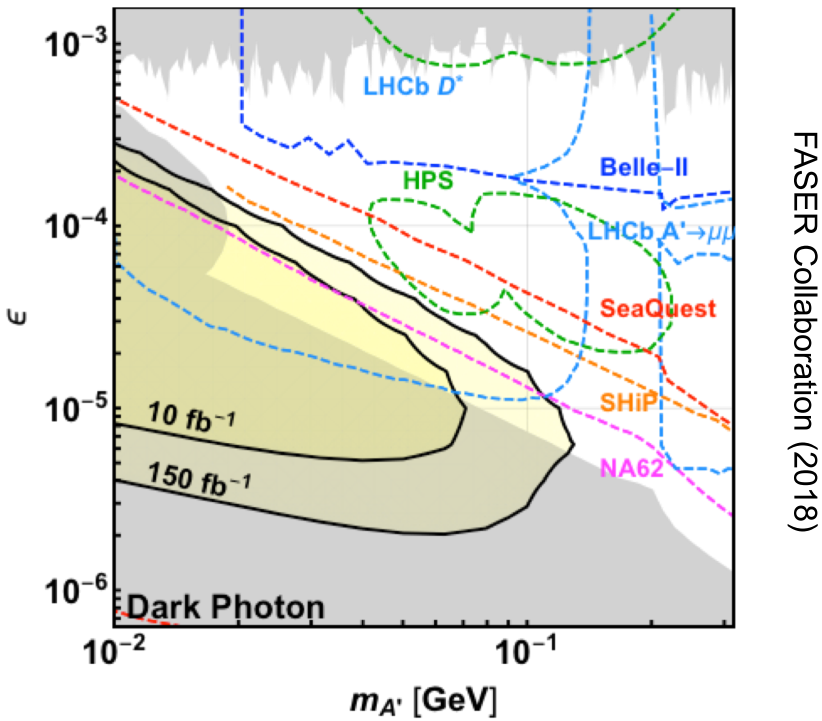
- Enormous event rates: $N_\pi \sim 10^{15}$ per bin
- Production is peaked at low transverse momentum ~250 MeV

- Rates highly suppressed by $\varepsilon^2 \sim 10^{-10}$
- But still $N_{A'} \sim 10^5$ per bin; LHC is a dark photon factory!

- Rates suppressed again, but still $N_{A'} \sim 100$ signal events
- Signal is E~TeV A's within 20 cm of the line of sight

DARK PHOTON SENSITIVITY REACH



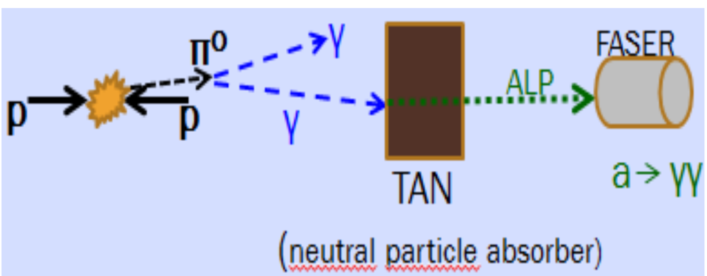


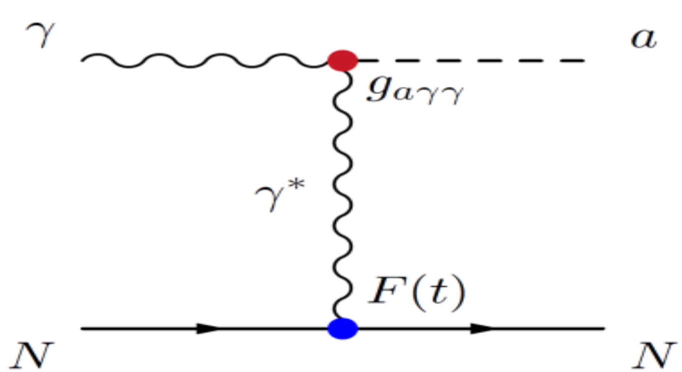
- FASER: R=10cm, L=1.5 m
- Even with 10 fb^{-1} (end of 2021) will have sensitivity to uncharted territory. With full Run 3 dataset (150 fb^{-1}), significant discovery potential.
- Discovery contours assume 100% signal efficiency, no background. But note: signal contours are very closely spaced: ~50% signal efficiency, off-center detector, … each lead to nearly imperceptible shifts in reach.

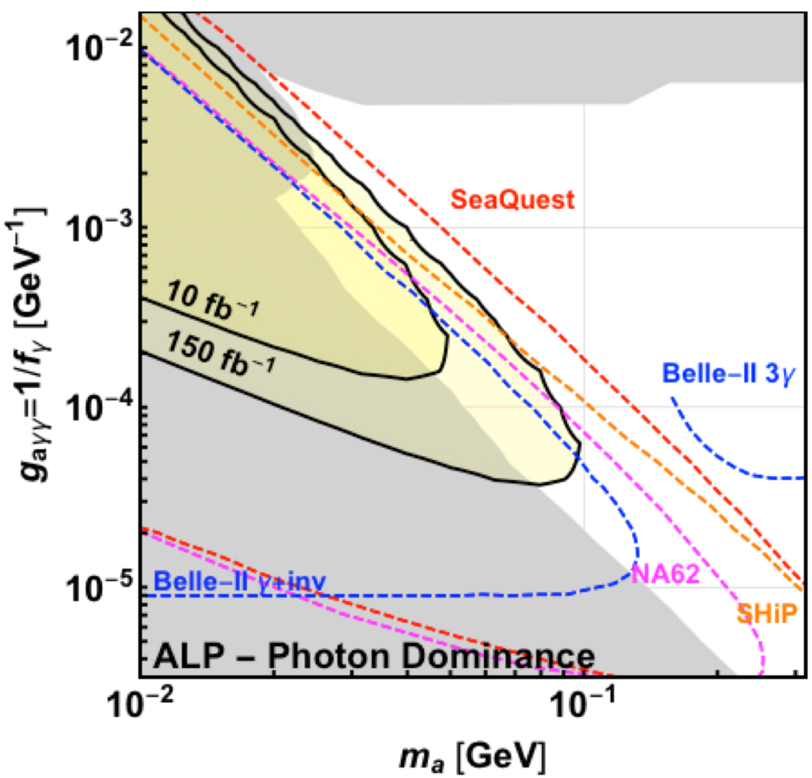
SIGNALS: ALPS COUPLED TO PHOTONS

- ~TeV photon from IP travels ~100 m, collides with TA(X)N, creates ALP through Primakoff process and a → $\gamma\gamma$ in FASER: a "light shining through (100 m) wall experiment."

- Signal is 2 photons separated by 0.1 – few mm. Distinguishing 2 photons is very challenging, but already some FASER upgrades proposed.



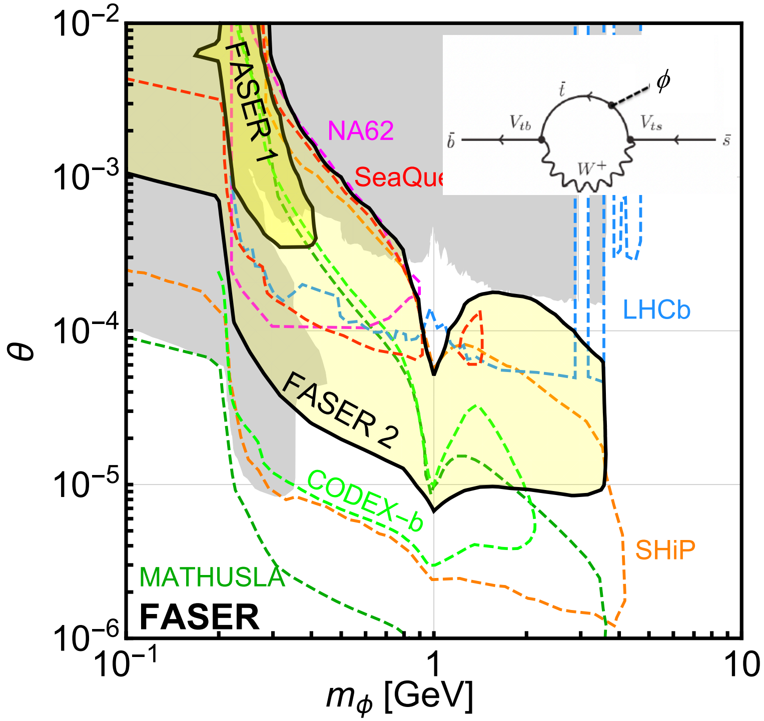




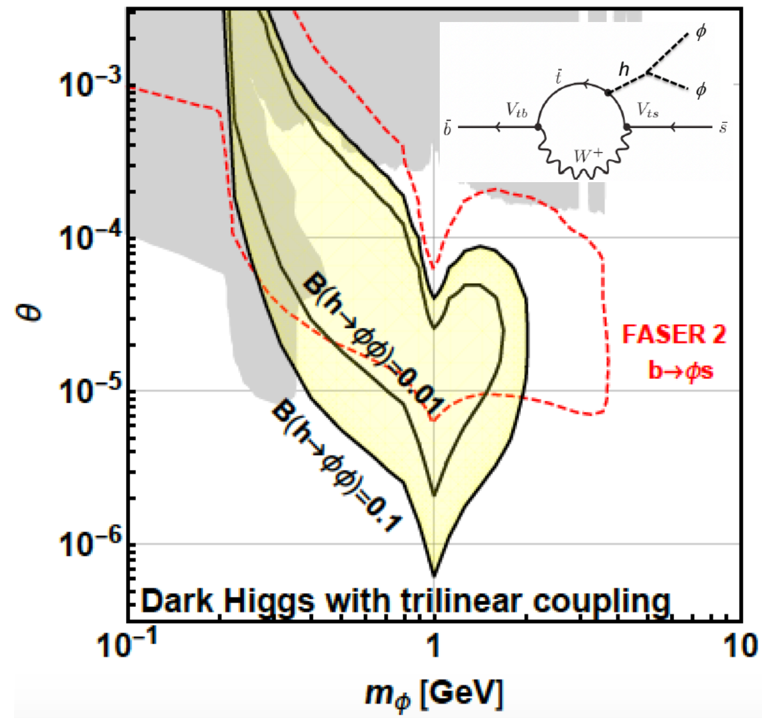
Feng, Galon, Kling, Trojanowski (2018)

SIGNALS: DARK HIGGS BOSONS

- **SINGLE PRODUCTION**



- **DOUBLE PRODUCTION**



Feng, Galon, Kling, Trojanowski (2017)

- With upgrade to FASER 2 detector, R=1m, L=5m, can probe new particles produced in D and B decays: $N_B/N_\pi \sim 10^{-2}$ at FASER ($N_B/N_\pi \sim 10^{-7}$ at beam dumps)
- Signal is $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^-

- Probes $h\phi\phi$ trilinear coupling
- Complementary to probes of exotic Higgs decays $h\to\phi\phi$
- FASER probes SM Higgs properties!

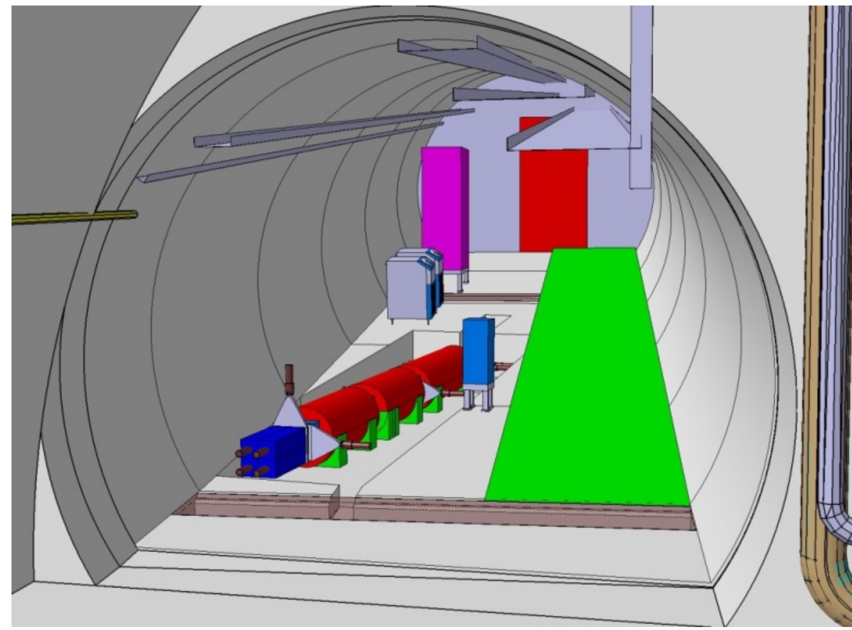
PHYSICS SUMMARY

- FASER has a full physics program: can discover all candidates with renormalizable couplings (dark photon, dark Higgs, HNL); ALPs with all types of couplings (γ, f, g); and many other examples; see FASER's Physics Reach for LLPs, 1811.12522.

Benchmark Model	FASER	FASER 2	References
V1/BC1: Dark Photon	√	√	Feng, Galon, Kling, Trojanowski, 1708.09389
V2/BC1': $U(1)_{B-L}$ Gauge Boson	√	√	Bauer, Foldenauer, Jaeckel, 1803.05466 FASER Collaboration, 1811.12522
BC2: Invisible Dark Photon	–	–	–
BC3: Milli-Charged Particle	–	–	–
S1/BC4: Dark Higgs Boson	–	√	Feng, Galon, Kling, Trojanowski, 1710.09387 Batell, Freitas, Ismail, McKeen, 1712.10022
S2/BC5: Dark Higgs with hSS	–	√	Feng, Galon, Kling, Trojanowski, 1710.09387
F1/BC6: HNL with e	–	√	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
F2/BC7: HNL with μ	–	√	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
F3/BC8: HNL with τ	√	√	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
A1/BC9: ALP with photon	√	√	Feng, Galon, Kling, Trojanowski, 1806.02348
A2/BC10: ALP with fermion	√	√	FASER Collaboration, 1811.12522
A3/BC11: ALP with gluon	√	√	FASER Collaboration, 1811.12522

FASER IN TUNNEL TI12

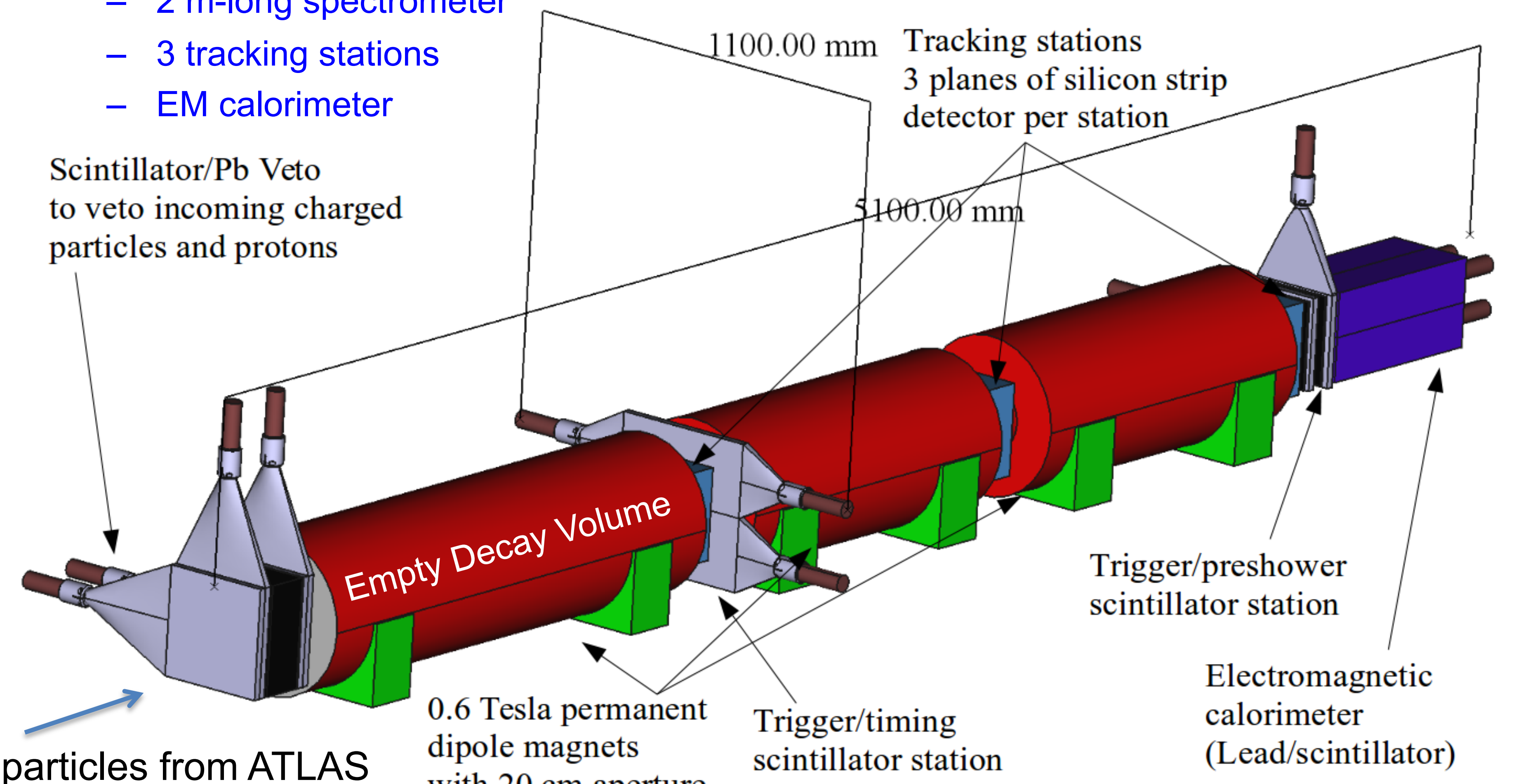
- The beam collision axis has been located to mm accuracy by the CERN survey department. To place FASER on this axis, a trench is required to lower the floor by 46 cm.



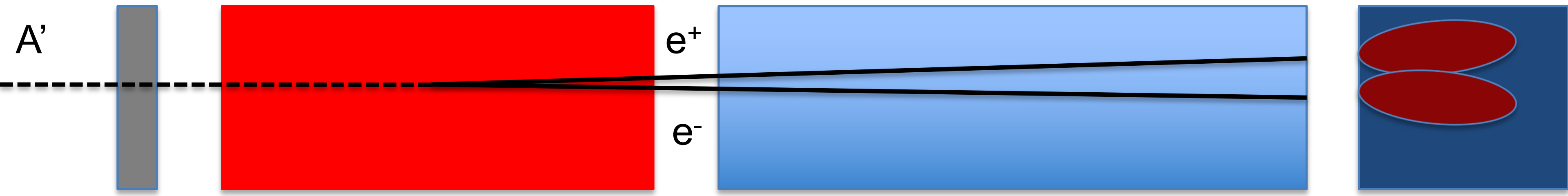
- The beam crossing angle also matters: if 285 (590) μrad, the "on axis" location at FASER shifts by 6 (12) cm.

THE FASER DETECTOR

- The detector consists of
  - Scintillator veto
  - 1.5 m-long decay volume
  - 2 m-long spectrometer
  - 3 tracking stations
  - EM calorimeter



THE SIGNAL



- The signal is spectacular: 2 ~TeV-energy, oppositely-charged tracks originating from a common vertex in the decay volume and with a combined momentum pointing back to the IP

- No signal in the veto scintillator

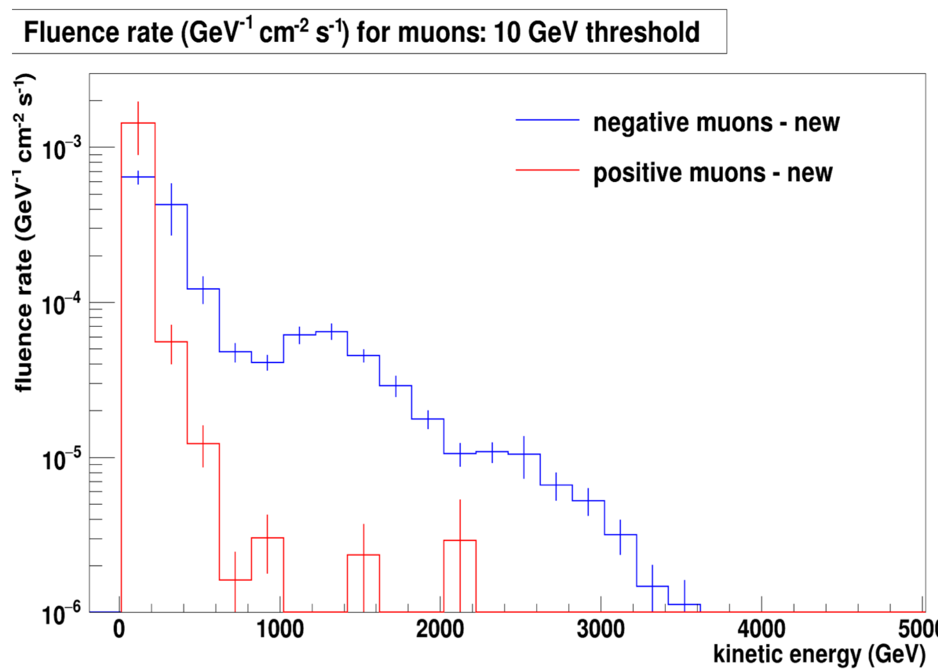
- For e^+e^- signature, also a large EM deposit in the calorimeter

- Magnets separate the 2 charged tracks sufficiently to resolve them in the tracker

$$h_B \approx \frac{ec\ell^2}{E} B = 3 \text{ mm} \left[\frac{1 \text{ TeV}}{E}\right] \left[\frac{\ell}{10 \text{ m}}\right]^2 \left[\frac{B}{0.1 \text{ T}}\right]$$

BACKGROUNDS

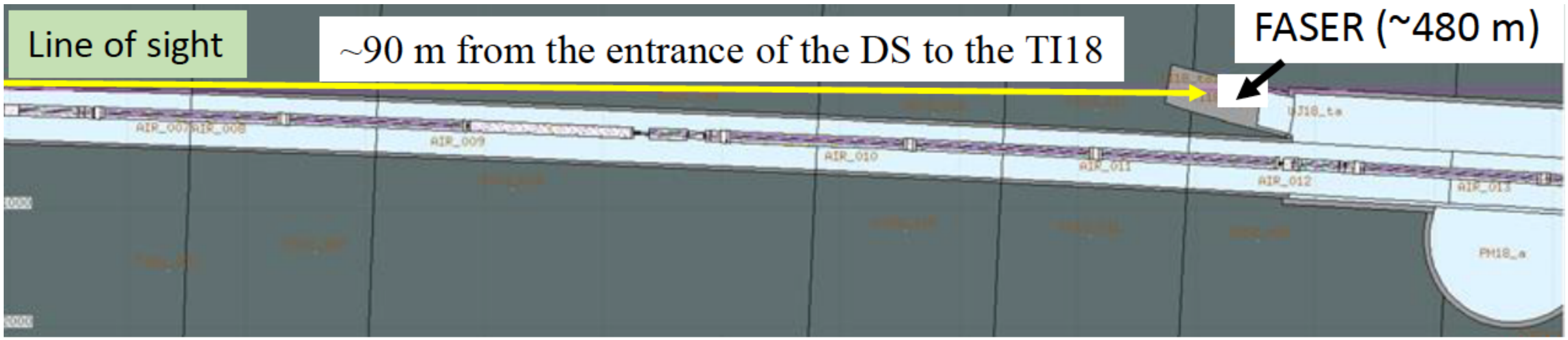
- FASER's location is very quiet – the only SM particles that get through from the IP are muons and neutrinos.
- A high-energy muon that brems off a photon or an EM or hadronic jet is a leading background if the incoming muon is not vetoed.
- But, assuming each of 4 scintillator layers gives an uncorrelated 10^{-2} veto suppression for muons entering the detector, the resulting backgrounds appear to be negligible.



FLUKA study: Sabate-Gilarte, Cerutti, Tsinganis (2018)

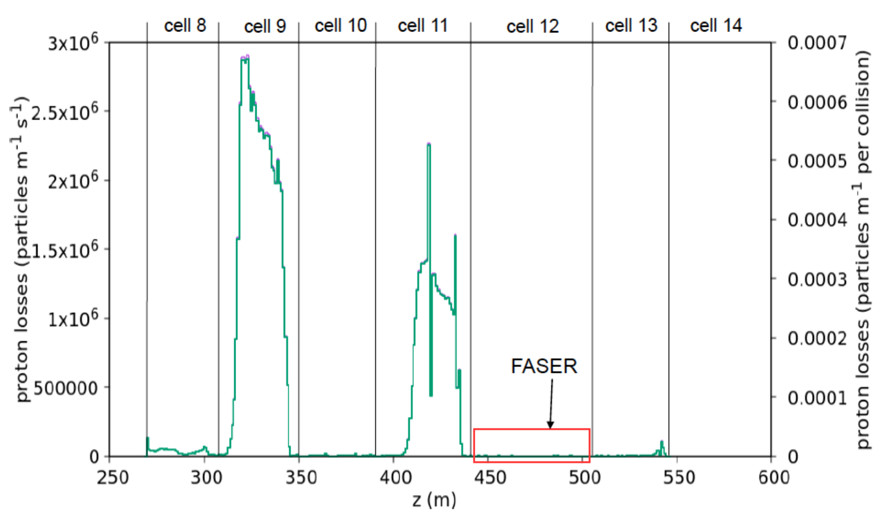
MORE BACKGROUNDS

- The FLUKA study also finds that beam-gas background (from “beam 2” traveling in the other direction) is also negligible.



- The dispersion of the machine means activity near FASER from diffractive proton losses is very small. It would be much higher 50m along LHC in either direction. The radiation level is low (<10^{-2} Gy/year), which is encouraging for detector electronics.

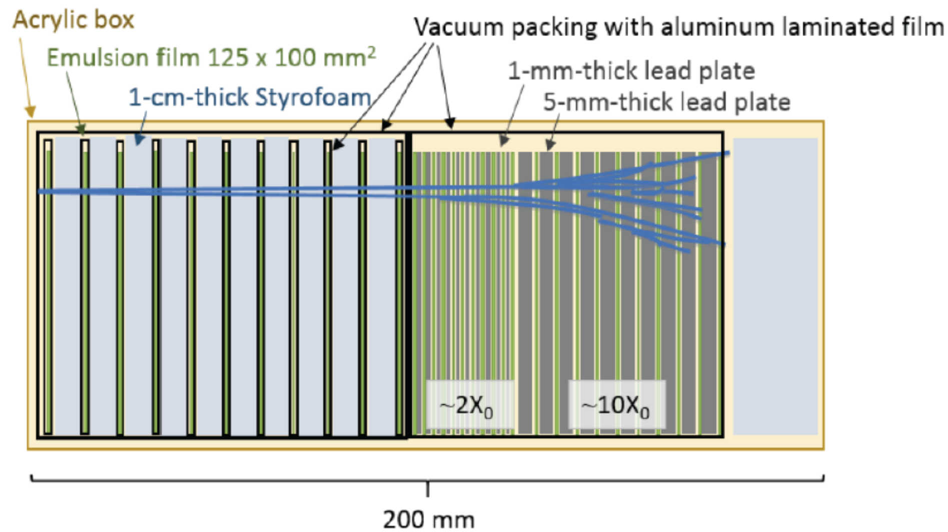
Proton-loss map in the DS

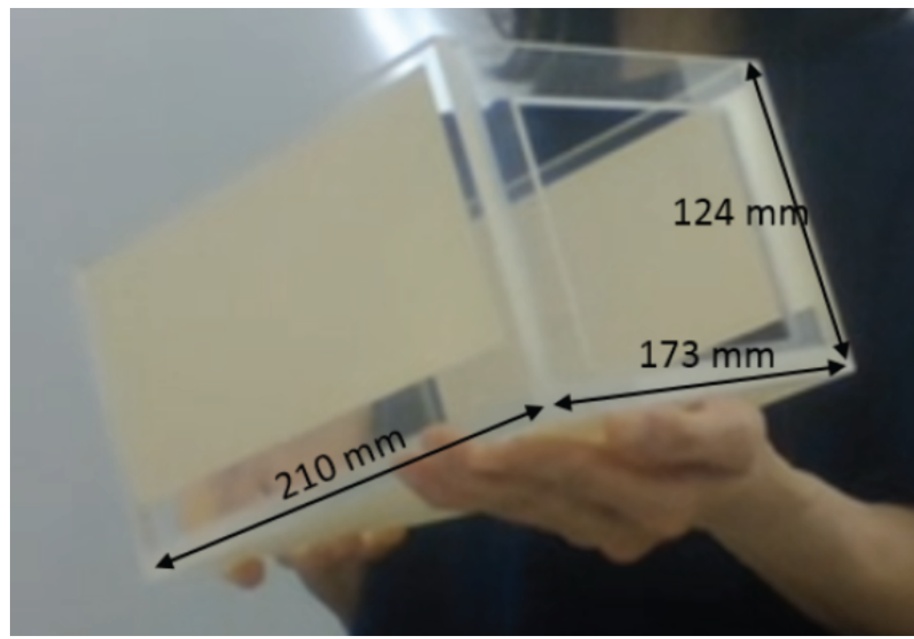


Sabate-Gilarte, Cerutti, Tsinganis (2018)

IN SITU MEASUREMENTS

- To validate the FLUKA background study, in 2018 we installed detectors in (weeklong) Technical Stops 1 and 2 to provide the first *in situ* measurements at the FASER site.
- An emulsion detector was prepared and placed at the FASER location.
- A BatMon (battery-operated radiation monitor) was also installed.



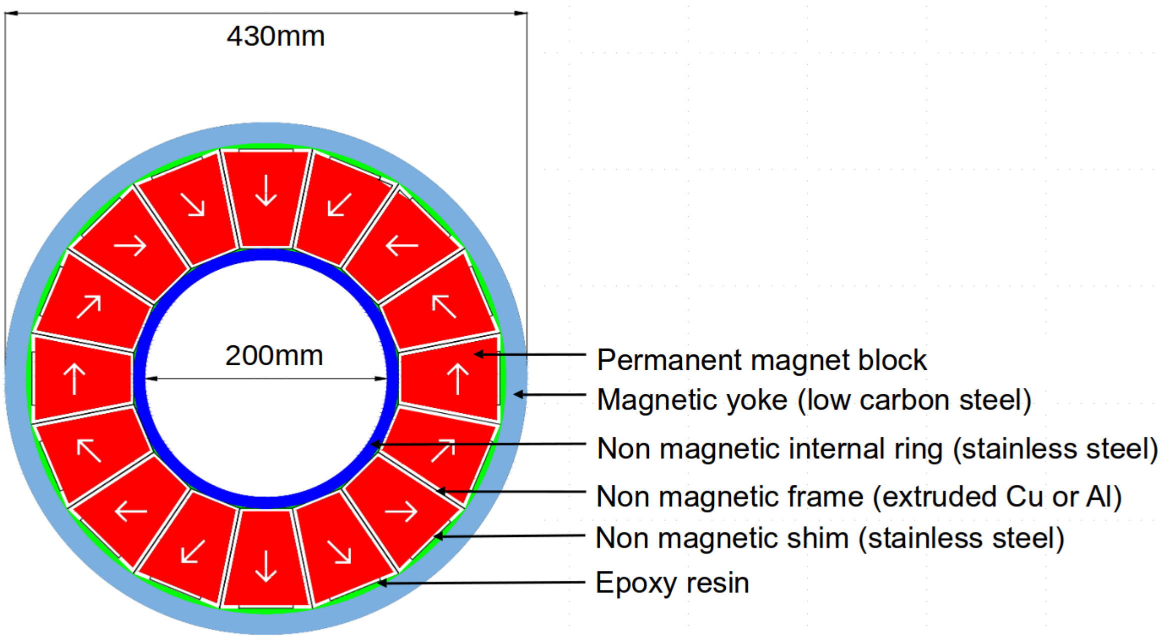


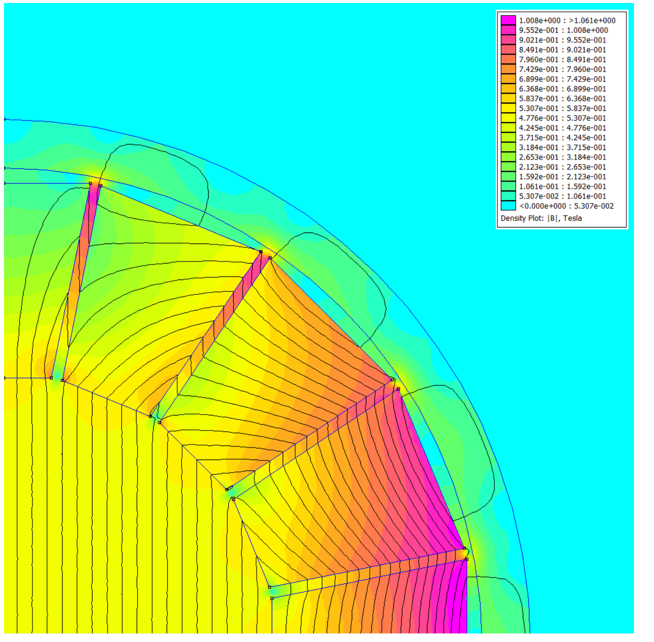
IN SITU MEASUREMENTS

- The emulsion detector results are within measurement accuracy (factor of 2) of the FLUKA predictions.

- The BatMon results for low-energy radiation are also promisingly low.

FASER MAGNETS

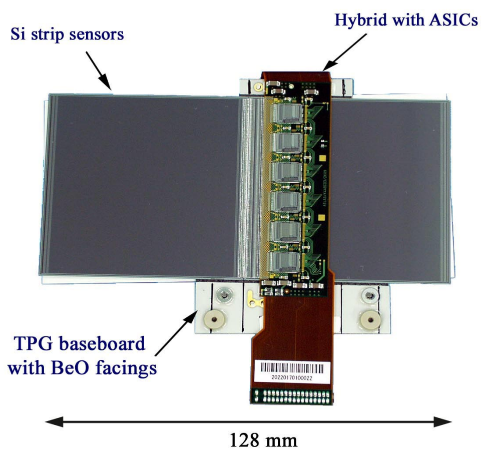




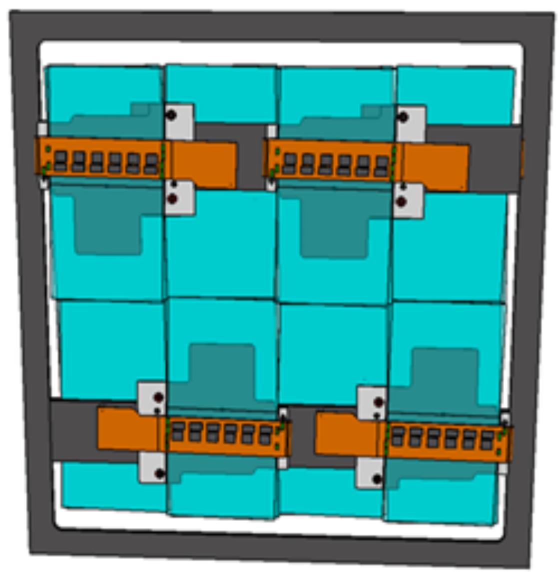
- The FASER magnets are 0.6T SmCo permanent dipole magnets based on the Halbach array design.
  - They are thin enough to allow the LOS to pass through the magnet center with minimum digging to the floor in TI12
  - Minimizes needed services (power, cooling etc..)
- Design and construction by the CERN magnet group.

FASER TRACKER

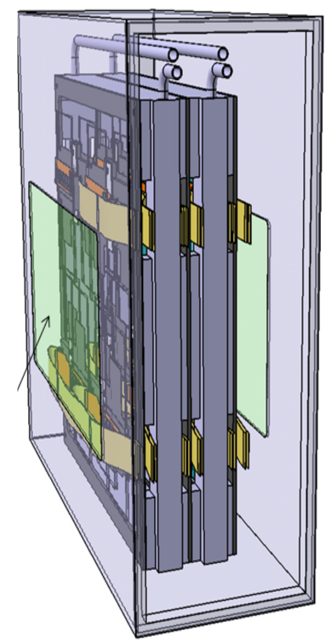
- The FASER tracker is composed of spare SCT modules from ATLAS. About 350 spares were prepared. They were not needed, and the ATLAS SCT collaboration has allowed us to use 80 of them. QA now completed.
- 8 SCT modules make up a 24cm x 24cm tracking layer, 3 layers make up a tracking station, and FASER has 3 tracking stations.



SCT module

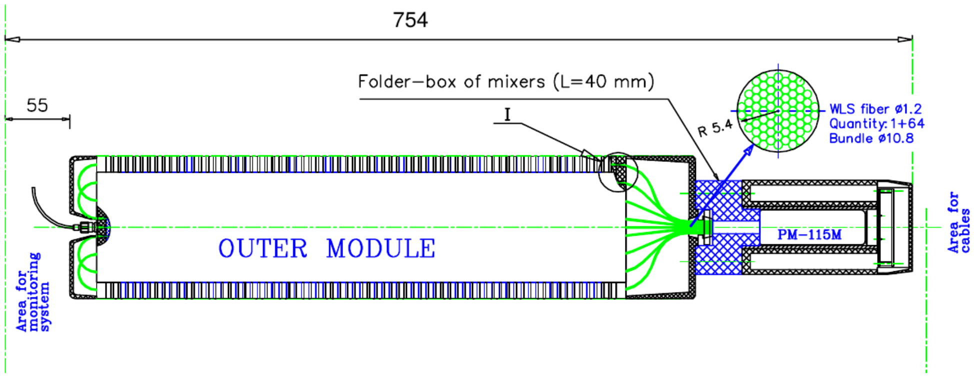


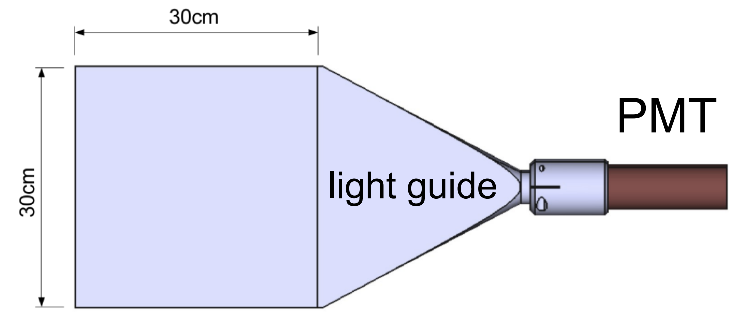
Tracking layer



Tracking station

FASER CALORIMETER / SCINTILLATORS

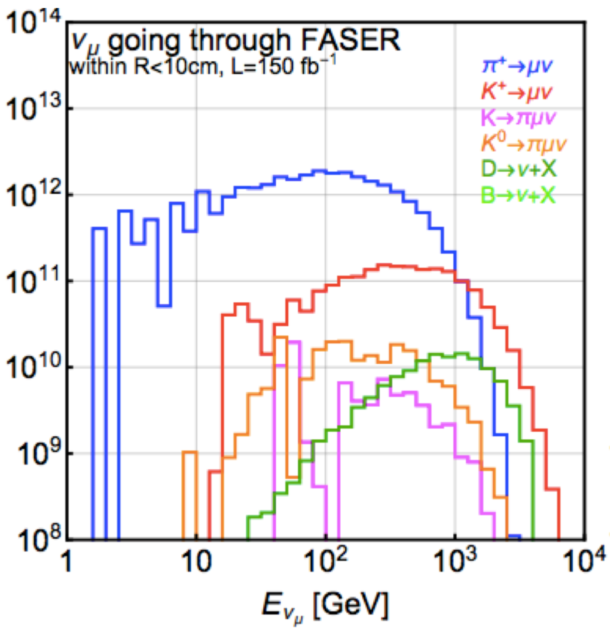


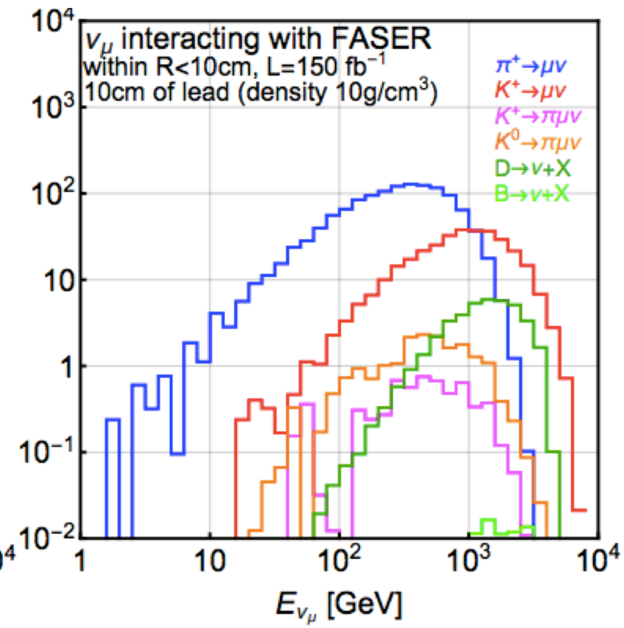


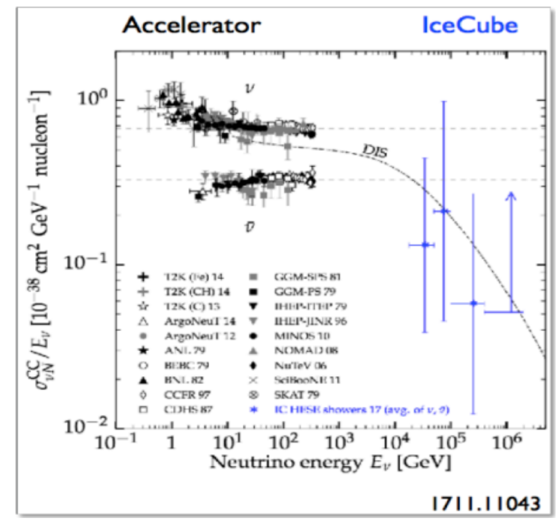
- The FASER ECAL consists of spare LHCb outer ECAL modules, which the LHCb Collaboration has allowed us to use.
  - Dimensions: 12cm x 12cm – 75cm long (including PMT)
  - 66 layers of lead/scintillator, light out by wavelength shifting fibres, and readout by PMT (no longitudinal shower information)
  - 25 radiation lengths long
  - Provides ~1% energy resolution for 1 TeV electrons

- Scintillators used for vetoing charged particles entering the decay volume and for triggering, to be produced by the CERN scintillator lab.

NEUTRINO MEASUREMENTS



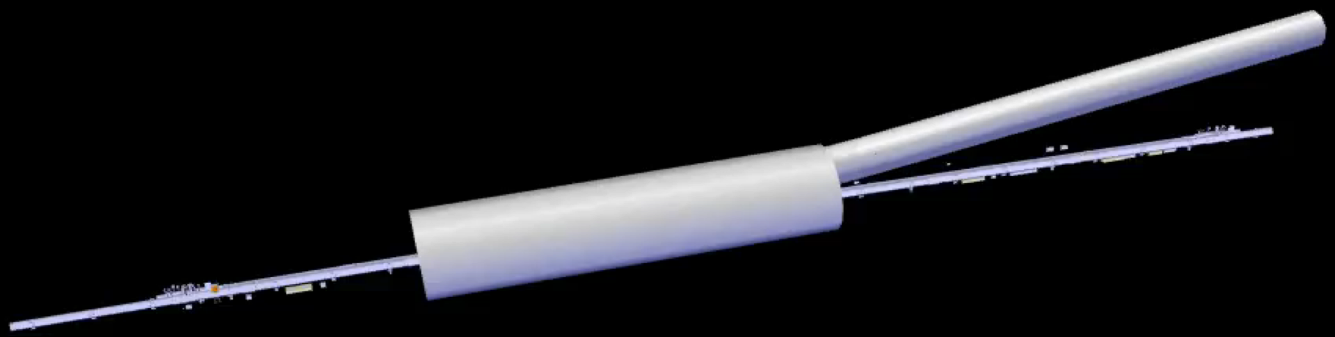




- Huge flux of high-energy neutrinos through FASER could allow for the 1st detection of an LHC neutrino and other interesting measurements, e.g., ν_μ CC cross section in unexplored region E>400 GeV, ν_τ events.
- In fact, we are already looking for neutrino interactions in the 30 kg emulsion detectors installed in TI12 in 2018. In 12.8 fb^{-1} of data, we expect ~10 ν_μ events.

FASER INSTALLATION

Dougherty, CERN Integration (2019)

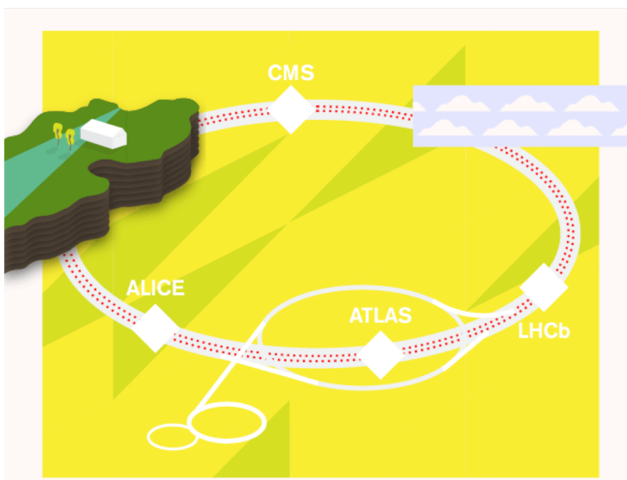


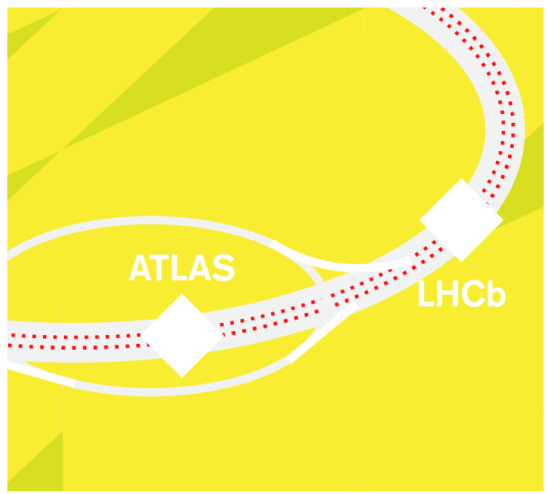
SUMMARY AND OUTLOOK

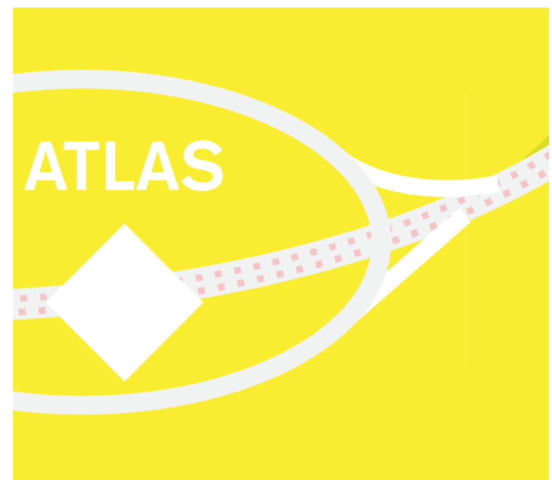
- A new target for particle physics experiments: light and weakly-interacting particles at the lifetime frontier.

- Fast, small, cheap experiments can provide world-leading sensitivities.

- FASER: 18 months from theory paper to beginning of construction, fits on a tabletop, ~$2M. Data-taking begins 2021 with discovery prospects for new matter and forces – we are looking forward to new physics!







Branigan, Sandbox Studio (2019)

- More info: https://twiki.cern.ch/twiki/bin/viewauth/FASER/WebHome.