PBC BSM Meeting, 20 October 2021

Jonathan Feng, UC Irvine

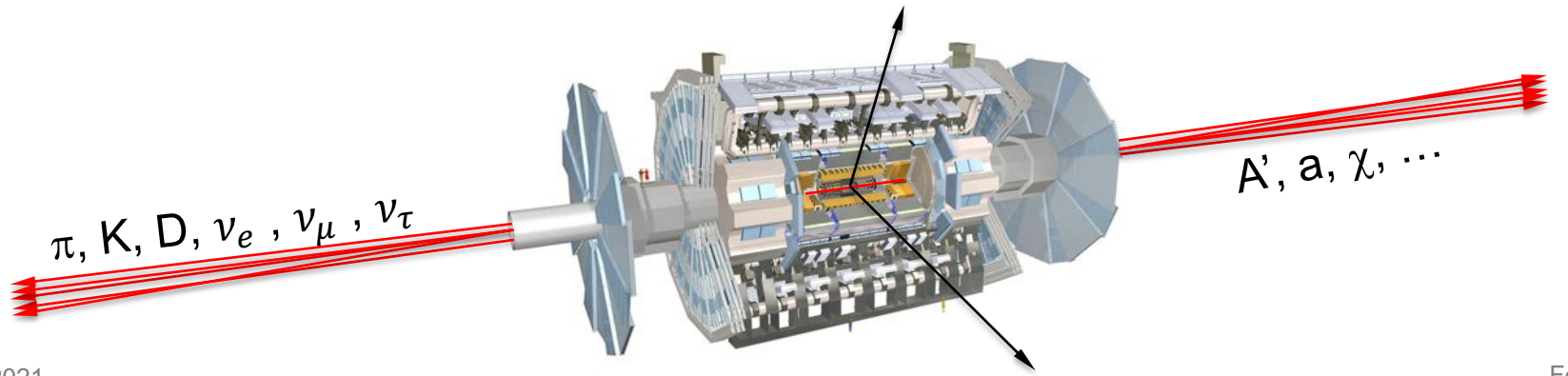
SIMONS FOUNDATION

HEISING-SIMONS FOUNDATION

SOME HISTORY

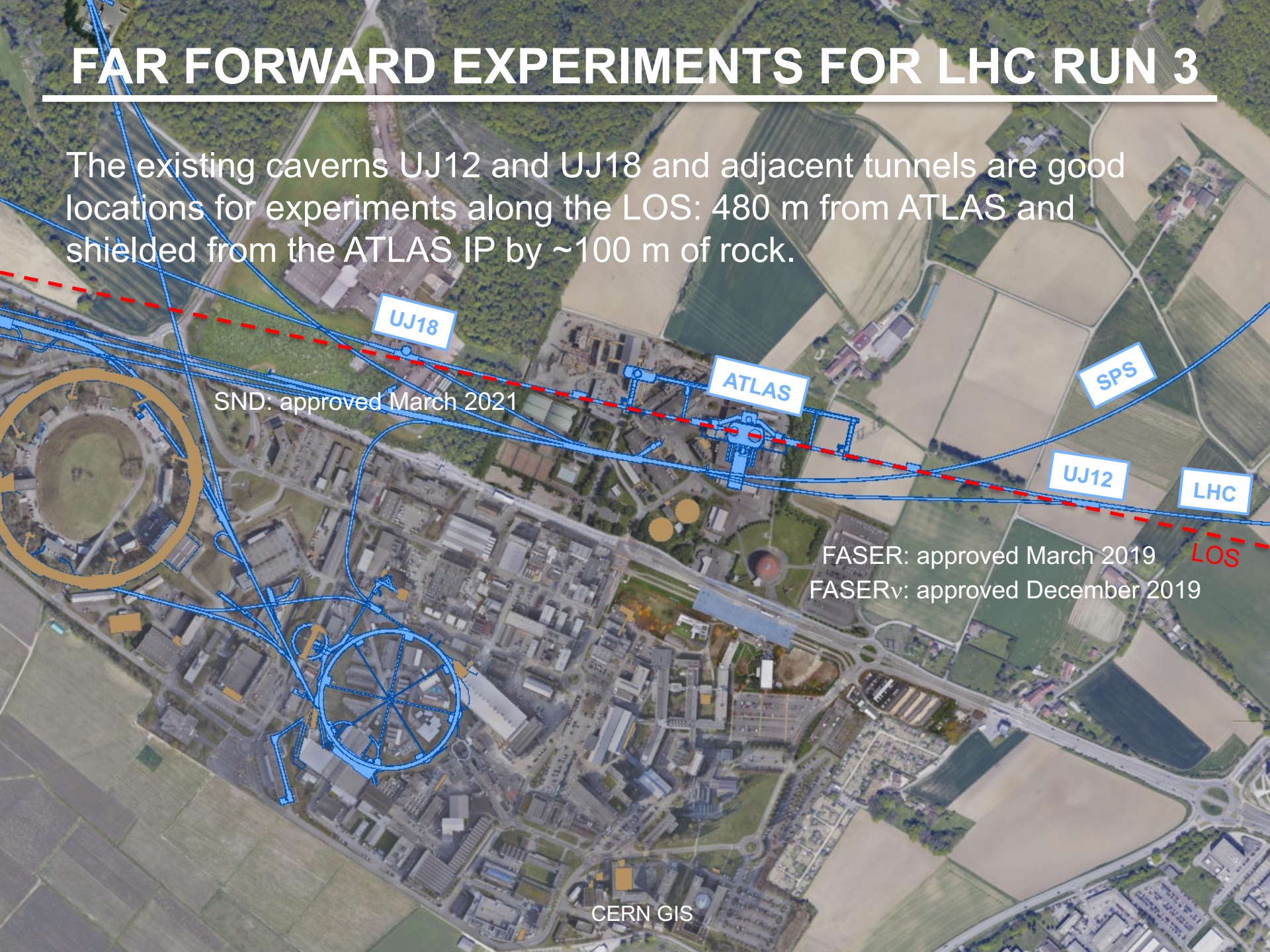
- On the Occasion of the 50th Anniversary of CERN's ISR:
  - "There was initially a broad belief that physics action would be in the forward directions at a hadron collider…. It is easy to say after the fact, still with regrets, that with an earlier availability of more complete…experiments at the ISR, CERN would not have been left as a spectator during the famous November revolution of 1974 with the J/ψ discoveries at Brookhaven and SLAC." -- Lyn Evans and Peter Jenni, "Discovery Machines," CERN Courier (2021).

- Are we missing opportunities in a similar (but opposite) way at the LHC?
  - By far the largest flux of energetic light particles (pions, neutrinos, and maybe also dark photons, ALPs, dark matter, …) is in the far-forward direction.

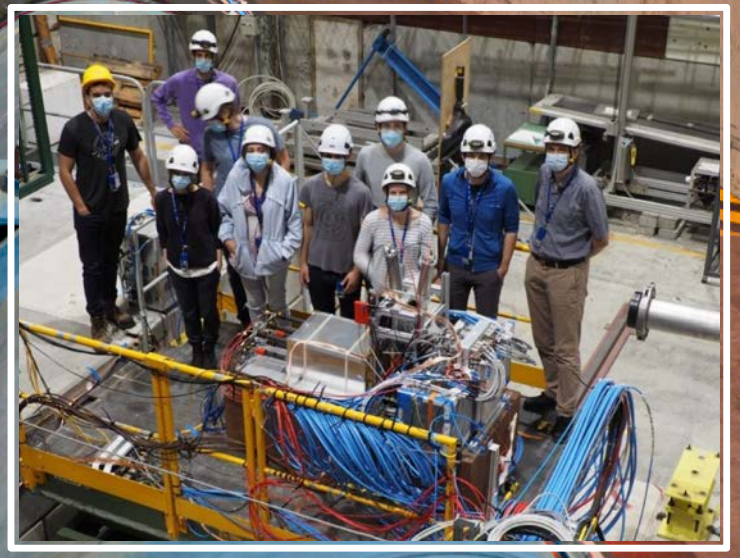


FAR FORWARD EXPERIMENTS FOR LHC RUN 3

The existing caverns UJ12 and UJ18 and adjacent tunnels are good locations for experiments along the LOS: 480 m from ATLAS and shielded from the ATLAS IP by ~100 m of rock.



FASER INSTALLATION COMPLETED IN MARCH 2021
TEST BEAM RUN COMPLETED AUGUST 2021



FASERν

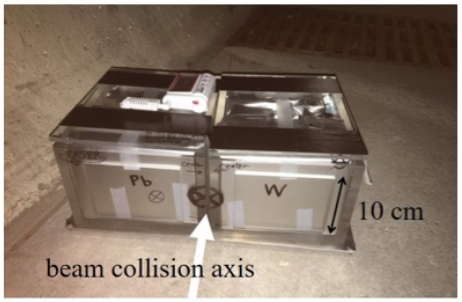
- In 2018 a 29 kg (11 kg fiducial) FASERν pilot emulsion detector collected data for 4 weeks on the beam collision axis.
- In May 2021, we announced the first direct detection of 6 neutrino candidates above expected background events (2.7σ).
- Not the 5σ discovery of collider neutrinos, but a promising sign of things to come!

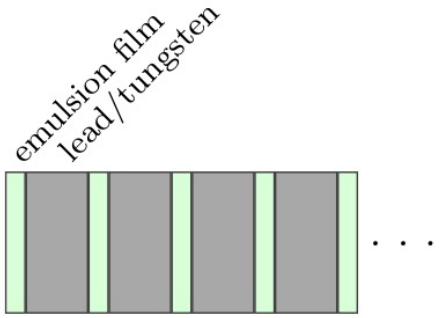
2105.06197

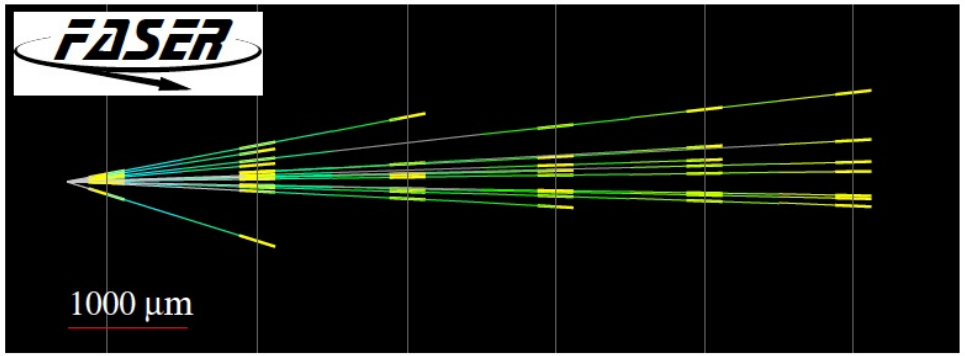
UCI-TR-2021-04, KYUSHU-RCAPP-2020-04, CERN-EP-2021-087

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)





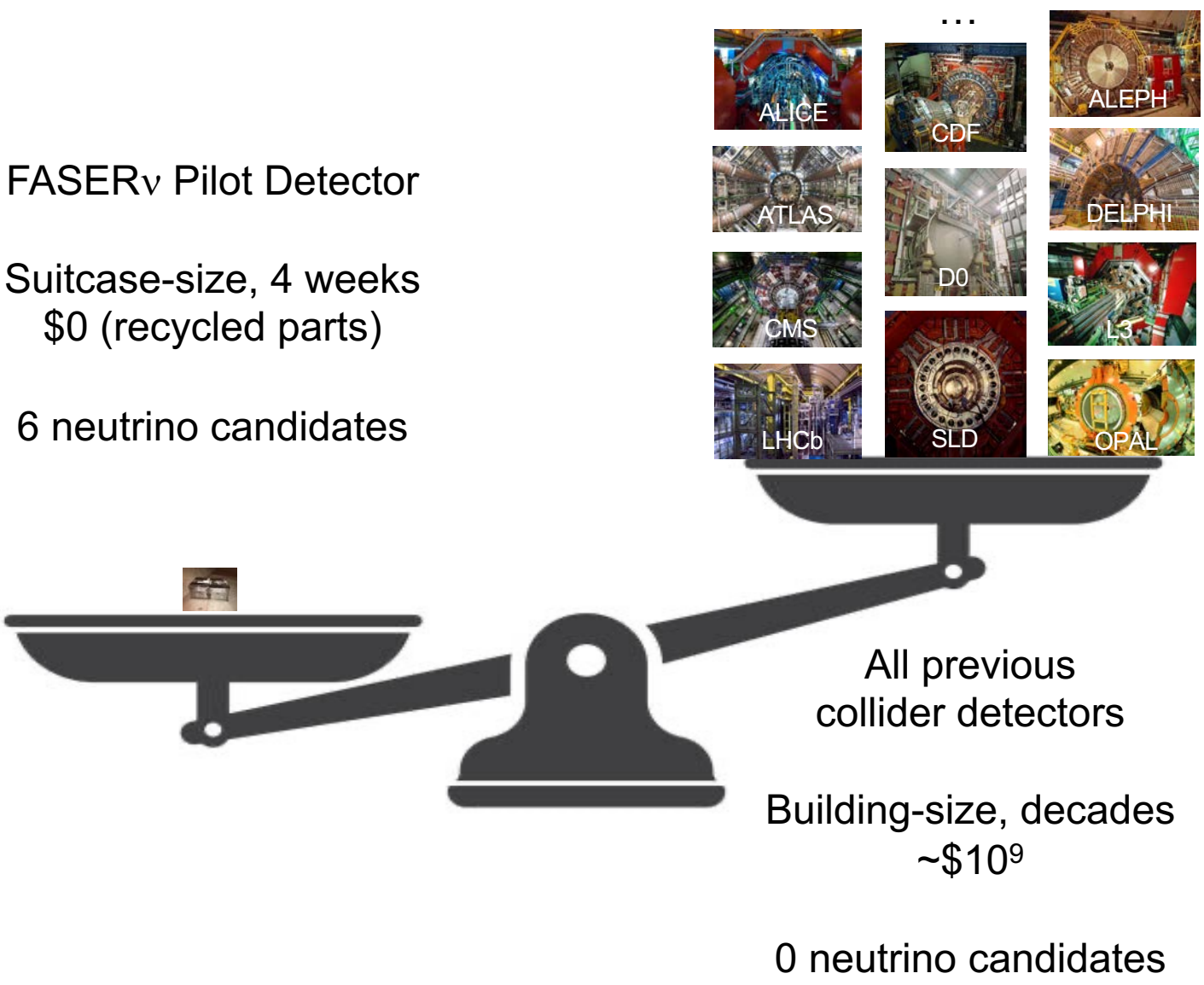


LOCATION, LOCATION, LOCATION

FASERν Pilot Detector

Suitcase-size, 4 weeks
$0 (recycled parts)

6 neutrino candidates



All previous
collider detectors

Building-size, decades
~10^9

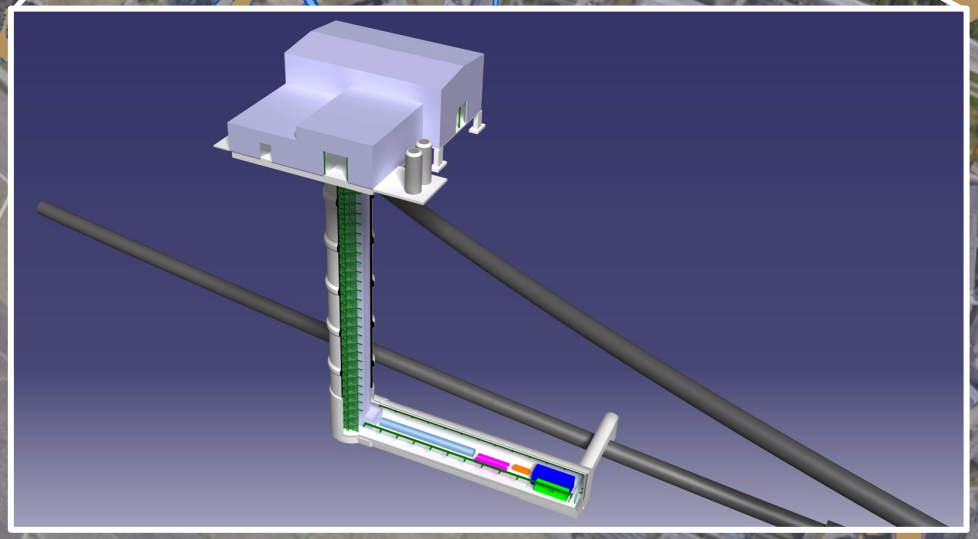
0 neutrino candidates

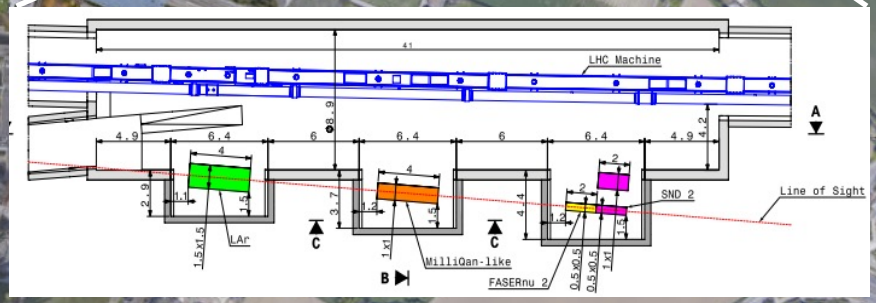
FORWARD PHYSICS FACILITY FOR HL-LHC

Possibilities presented by CERN CE at FPF2 Meeting:

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

(2) create a new shaft and cavern ~617 m from ATLAS past UJ18





CERN GIS

See Kincso Balazs talk,
FPF2 Meeting, 27-28 May 2021

FPF "SHORT PAPER"

- The status of the FPF has been summarized in a 75-page "short paper": not a compilation of every relevant study, but rather a distillation of key progress on the FPF so far.

2109.10905

- Written over ~3 months by ~80 co-authors, it summarizes the facility, experiments, and physics potential of the FPF.

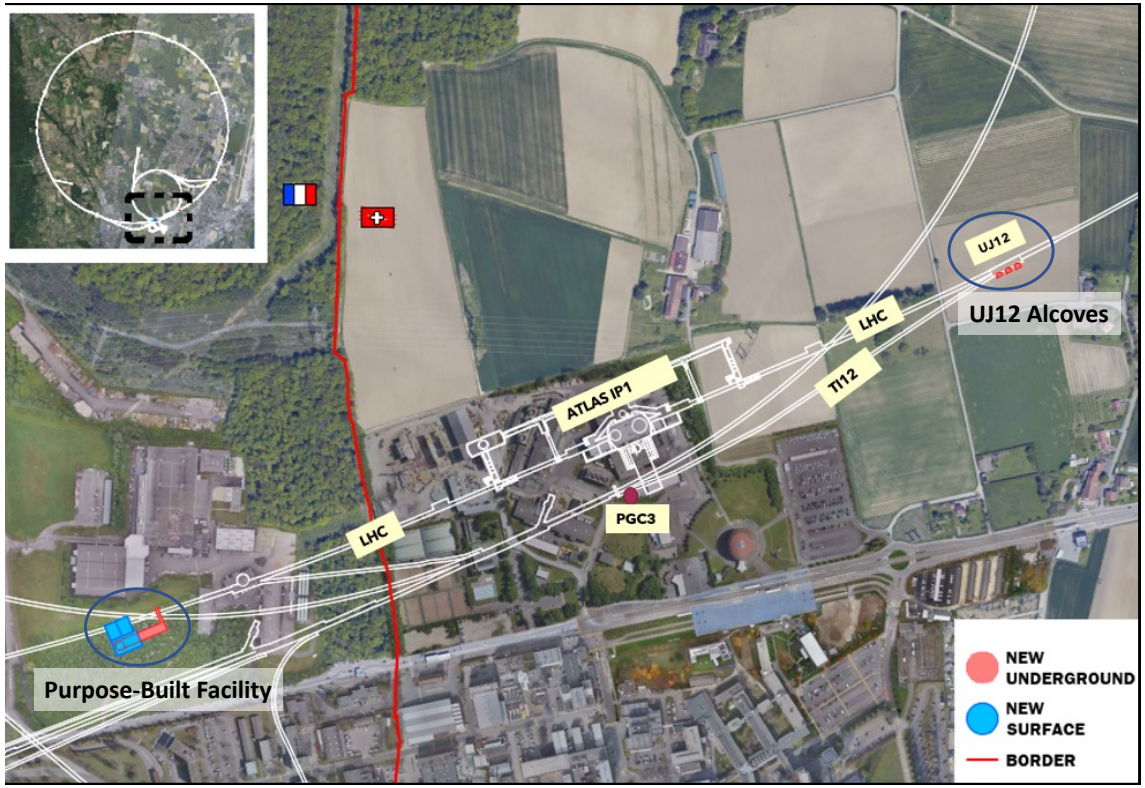
The Forward Physics Facility: Sites, Experiments, and Physics Potential

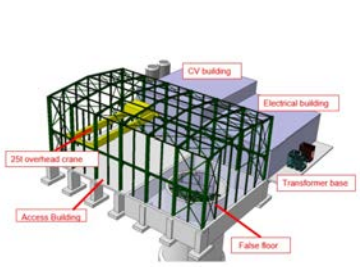
Luis A. Anchordoqui,[1,*] Akitaka Ariga,[2,3] Tomoko Ariga,[4] Weidong Bai,[5] Kincso Balazs,[6] Brian Batell,[7] Jamie Boyd,[6] Joseph Bramante,[8] Adrian Carmona,[9] Mario Campanelli,[10] Francesco G. Celiberto,[11,12,13] Grigorios Chachamis,[14] Matthew Citron,[15] Giovanni De Lellis,[16,17] Albert de Roeck,[6] Hans Dembinski,[18] Peter B. Denton,[19] Antonia Di Crecsenzo,[16,17,6] Milind V. Diwan,[20] Liam Dougherty,[21] Herbi K. Dreiner,[22] Yong Du,[23] Rikard Enberg,[24] Yasaman Farzan,[25] Jonathan L. Feng,[26,†] Max Fieg,[26] Patrick Foldenauer,[27] Saeid Foroughi-Abari,[28] Alexander Friedland,[29,*] Michael Fucilla,[30,31] Jonathan Gall,[32] Maria Vittoria Garzelli,[33,‡] Francesco Giuli,[34] Victor P. Goncalves,[35] Marco Guzzi,[36] Francis Halzen,[37] Juan Carlos Helo,[38,39] Christopher S. Hill,[40] Ahmed Ismail,[41,*] Ameen Ismail,[42] Sudip Jana,[43] Yu Seon Jeong,[44] Krzysztof Jodłowski,[45] Fnu Karan Kumar,[20] Kevin J. Kelly,[46] Felix Kling,[29,47,§] Rafał Maciuła,[48] Roshan Mammen Abraham,[41] Julien Manshanden,[33] Josh McFayden,[49] Mohammed M. A. Mohammed,[30,31] Pavel M. Nadolsky,[50,*] Nobuchika Okada,[51] John Osborne,[6] Hidetoshi Otono,[4] Vishvas Pandey,[52,46,*] Alessandro Papa,[30,31] Digesh Raut,[53] Mary Hall Reno,[54,*] Filippo Resnati,[6] Adam Ritz,[28] Juan Rojo,[55] Ina Sarcevic,[56,*] Christiane Scherb,[57] Pedro Schwaller,[58] Holger Schulz,[59] Dipan Sengupta,[60] Torbjörn Sjöstrand,[61,*] Tyler B. Smith,[26] Dennis Soldin,[53,*] Anna Stasto,[62] Antoni Szczurek,[48] Zahra Tabrizi,[63] Sebastian Trojanowski,[64,65] Yu-Dai Tsai,[26,46] Douglas Tuckler,[66] Martin W. Winkler,[67] Keping Xie,[7] and Yue Zhang[66]

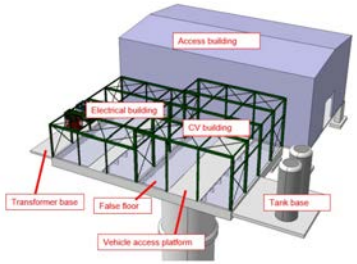
The Forward Physics Facility (FPF) is a proposal to create a cavern with the space and infrastructure to support a suite of far-forward experiments at the Large Hadron Collider during the High Luminosity era. Located along the beam collision axis and shielded from the interaction point by at least 100 m of concrete and rock, the FPF will house experiments that will detect particles outside the acceptance of the existing large LHC experiments and will observe rare and exotic processes in an extremely low-background environment. In this work, we summarize the current status of plans for the FPF, including recent progress in civil engineering in identifying promising sites for the FPF; the FPF experiments currently envisioned to realize the FPF's physics potential; and the many Standard Model and new physics topics that will be advanced by the FPF, including searches for long-lived particles, probes of dark matter and dark sectors, high-statistics studies of TeV neutrinos of all three flavors, aspects of perturbative and non-perturbative QCD, and high-energy astroparticle physics.

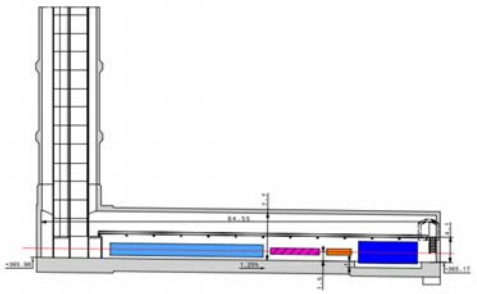
FPF SHORT PAPER: FACILITY

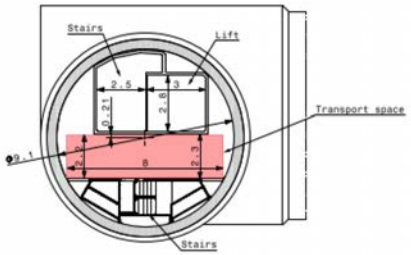
- Purpose-Built Facility on CERN land in France, 620 m east of ATLAS IP.
- ~70m long experimental hall along the LOS
- Description of the hall, shaft, surface buildings, services, safety.
- Very preliminary Class 4 cost estimate (including all services): 40 MCHF.





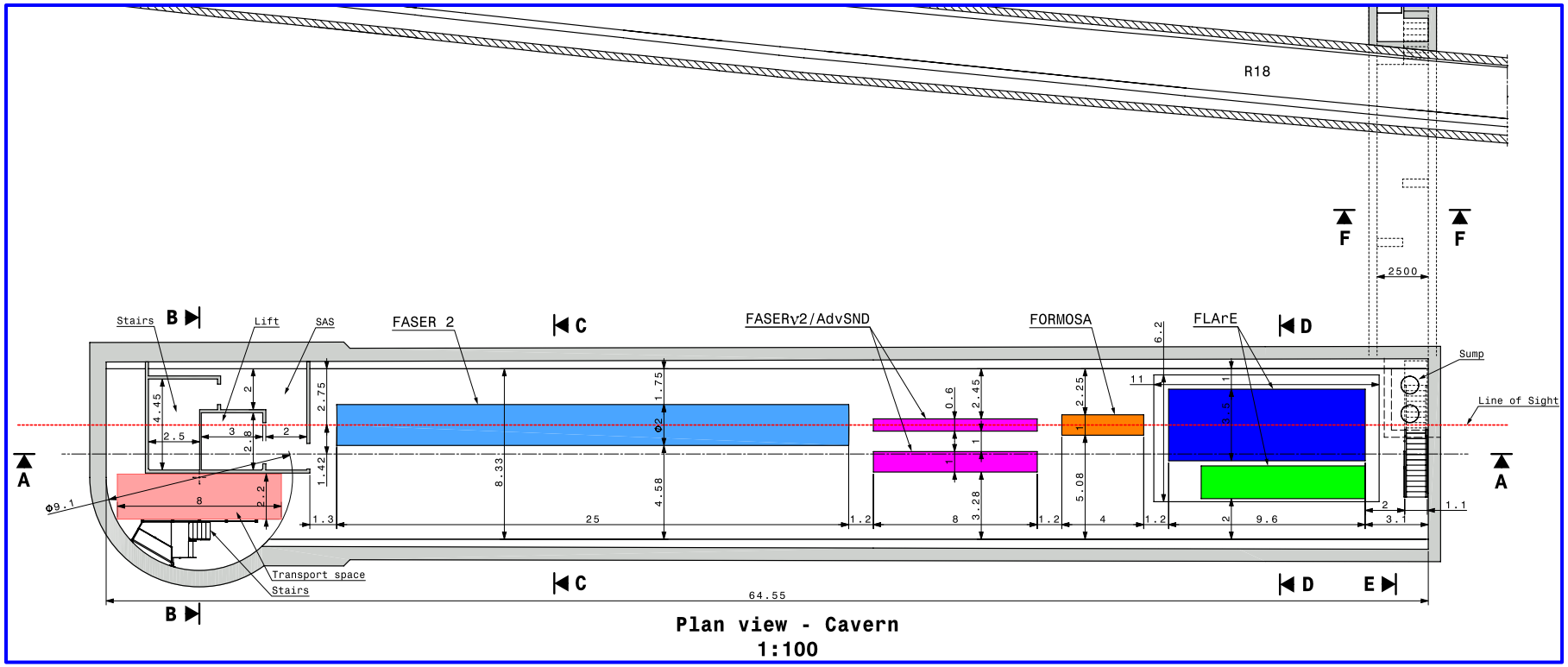






FPF SHORT PAPER: EXPERIMENTS

- FASER2: tracker, magnetic spectrometer, BSM LLP search
- FASERν2: ~20 tonne emulsion/tungsten detector, neutrinos, especially tau
- AdvSND: 2 ~2-10 tonne detectors (AdvSND1 in FPF, AdvSND2 at η~4.5), neutrinos
- FORMOSA: scintillator detector, millicharged particles, neutrino EDMs, etc.
- FLArE: ~10 tonne LArTPC, neutrinos, DM direct detection



FPF SHORT PAPER: PHYSICS

- Searches for New Physics
- Neutrino Physics
- QCD
- Astroparticle Physics

CONTENTS

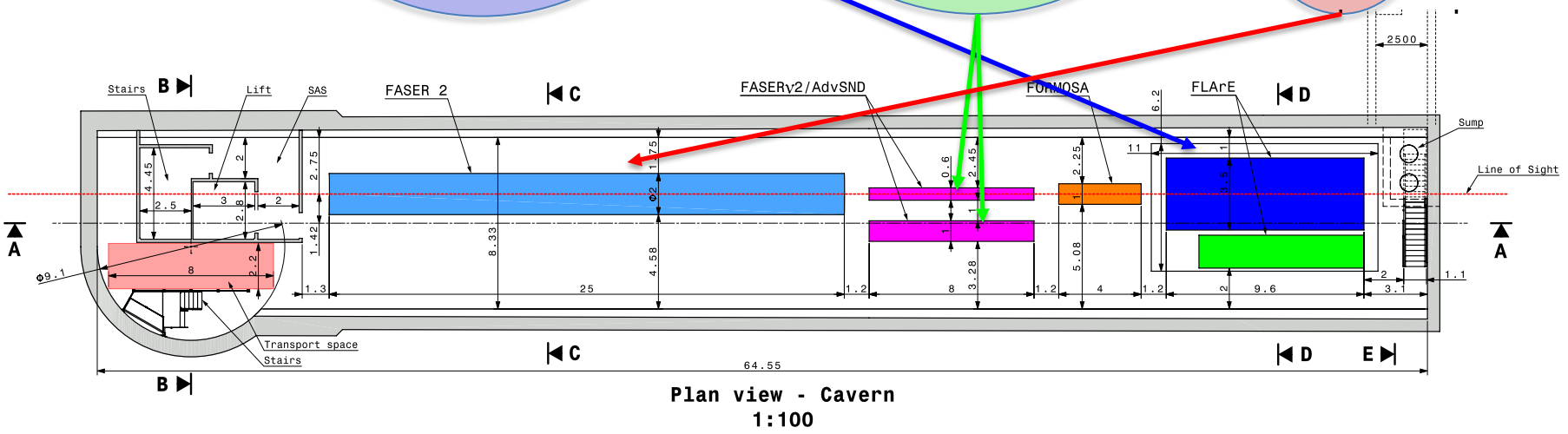
FPF BSM PHYSICS

- The FPF will accommodate experiments with sensitivity to BSM phenomena through LLP searches, but also through DM direct detection, and neutrino properties.

Benchmark Model	Underway	FPF	References
BC1: Dark Photon	FASER	FASER 2	Feng, Galon, Kling, Trojanowski, 1708.09389
BC1': $U(1)_{B-L}$ Gauge Boson	FASER	FASER 2	Bauer, Foldenauer, Jaeckel, 1803.05466 FASER Collaboration, 1811.12522
BC2: Dark Matter	–	FLArE	Batell, Feng, Trojanowski, 2101.10338 Batell et al., 2107.00666
BC3: Milli-Charged Particle	–	FORMOSA	Foroughi-Bari, Kling, Tsai, 2010.07941
BC4: Dark Higgs Boson	–	FASER 2	Feng, Galon, Kling, Trojanowski, 1710.09387 Batell, Freitas, Ismail, McKeen, 1712.10022
BC5: Dark Higgs with hSS	–	FASER 2	Feng, Galon, Kling, Trojanowski, 1710.09387
BC6: HNL with e	–	FASER 2	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC7: HNL with μ	–	FASER 2	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC8: HNL with τ	FASER	FASER 2	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC9: ALP with photon	FASER	FASER 2	Feng, Galon, Kling, Trojanowski, 1806.02348
BC10: ALP with fermion	FASER	FASER 2	FASER Collaboration, 1811.12522
BC11: ALP with gluon	FASER	FASER 2	FASER Collaboration, 1811.12522

BSM EXAMPLE: LIGHT $U(1)_{B-3\tau}$ GAUGE BOSON

Signature	DM DIS	DM Elastic	ν NC DIS	ν_τ CC DIS	LLP decays
Models	$U(1)_B$, $U(1)_{B-3\tau}$	$U(1)_B$, $U(1)_{B-3\tau}$	$U(1)_{B-3\tau}$	$U(1)_{B-3\tau}$	$U(1)_B$, $U(1)_{B-3\tau}$
Production	$pp \to V \to \chi\chi$	$pp \to V \to \chi\chi$	$pp \to D_s \to \nu_\tau$	$pp \to V \to \nu_\tau\bar{\nu}_\tau$	$pp \to V$
Detection	$\chi N \to \chi X$	$\chi p \to \chi p$	$\nu_\tau N \to \nu_\tau X$	$\nu_\tau N \to \tau X$	$V \to$ hadrons



Plan view - Cavern
1:100

Batell, Feng, Fieg, Ismail, Kling, Abraham, Trojanowski (in progress); see also talk of Sebastian Trojanowski

PLANS

- The FPF and related experiments have benefited greatly from PBC support. Hope for continued progress within the PBC framework and also the Snowmass community exercise.

- FPF meetings
  - FPF Kickoff Meeting, 9-10 Nov 2020, https://indico.cern.ch/event/955956
  - FPF2 Meeting, 27-28 May 2021, https://indico.cern.ch/event/1022352
  - FPF3 Meeting, 25-26 Oct 2021, https://indico.cern.ch/event/1076733

- The next meeting is this coming week and will include
  - Updates from civil engineering, RP studies, sweeper magnet
  - Progress from the experiments
  - New physics motivations from BSM, QCD, neutrino, astroparticle physics

- A white paper (~200-300 pages) will be submitted to Snowmass in February-March 2022.