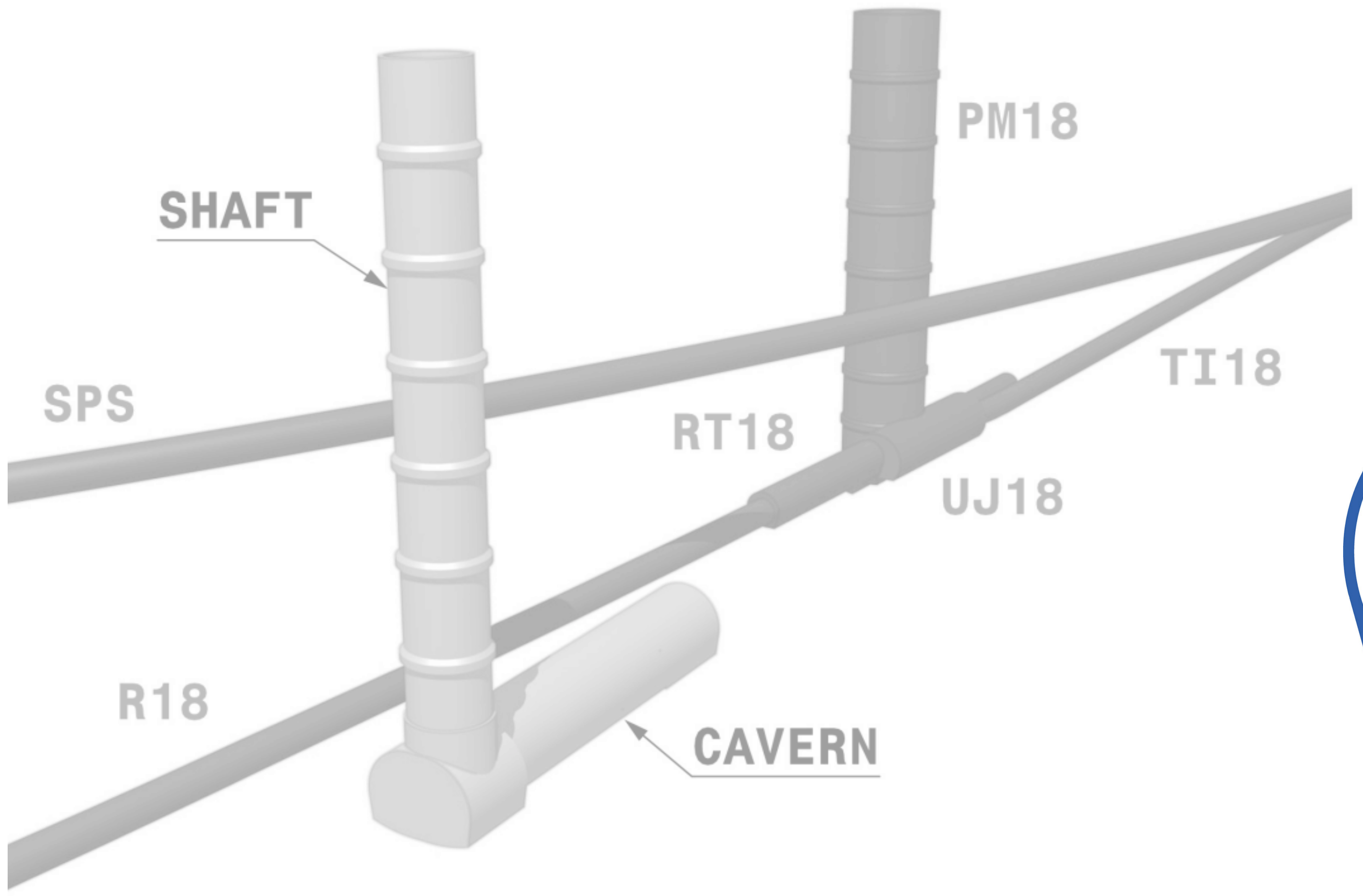
The Forward Physics Facility at the HL-LHC and its Connection to Astroparticle Physics

IAP-HEU Seminar, KIT
May 4, 2023

Dennis Soldin
ETP / IAP

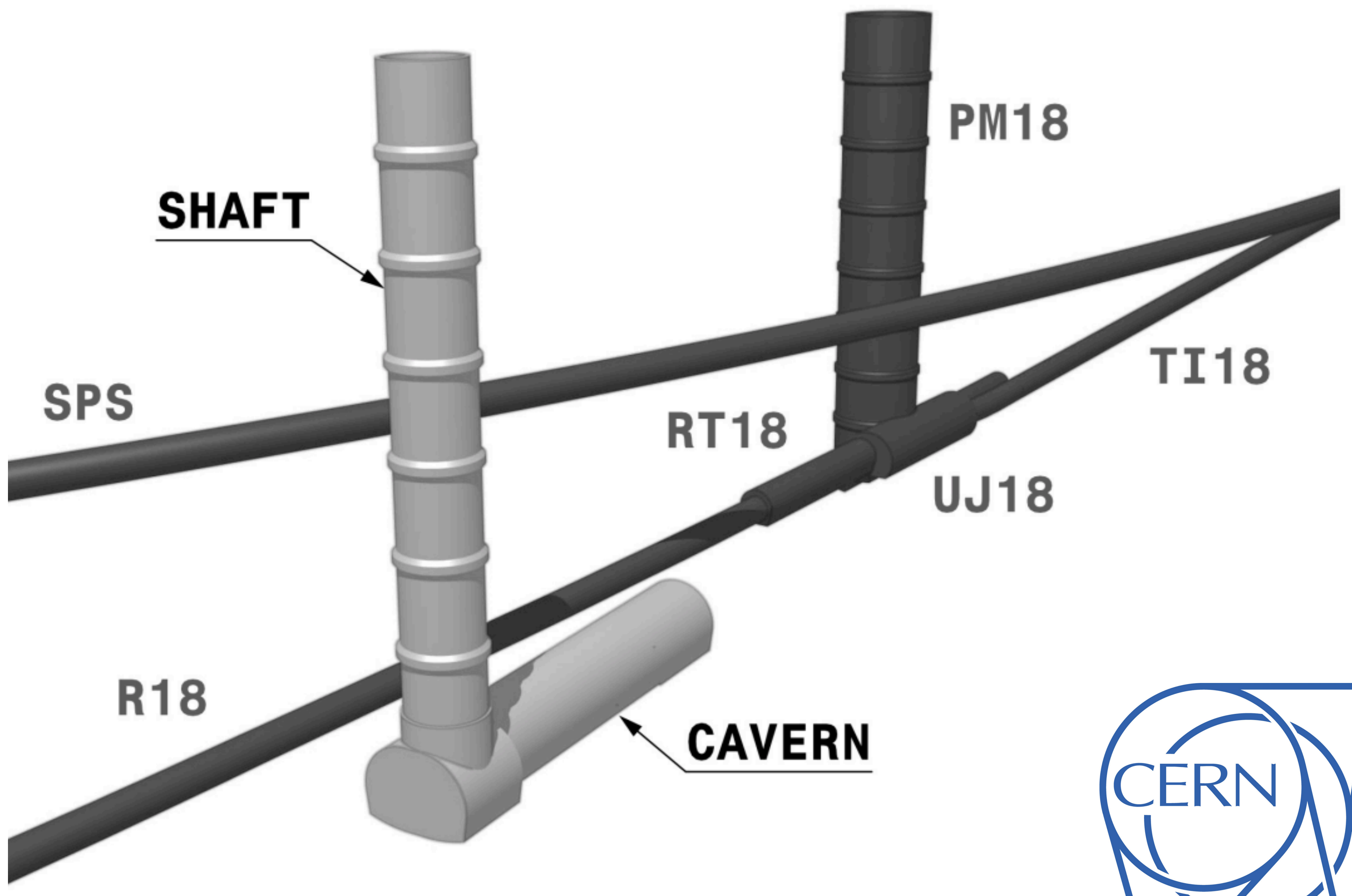


Karlsruher Institut für Technologie

Forward Physics Facility

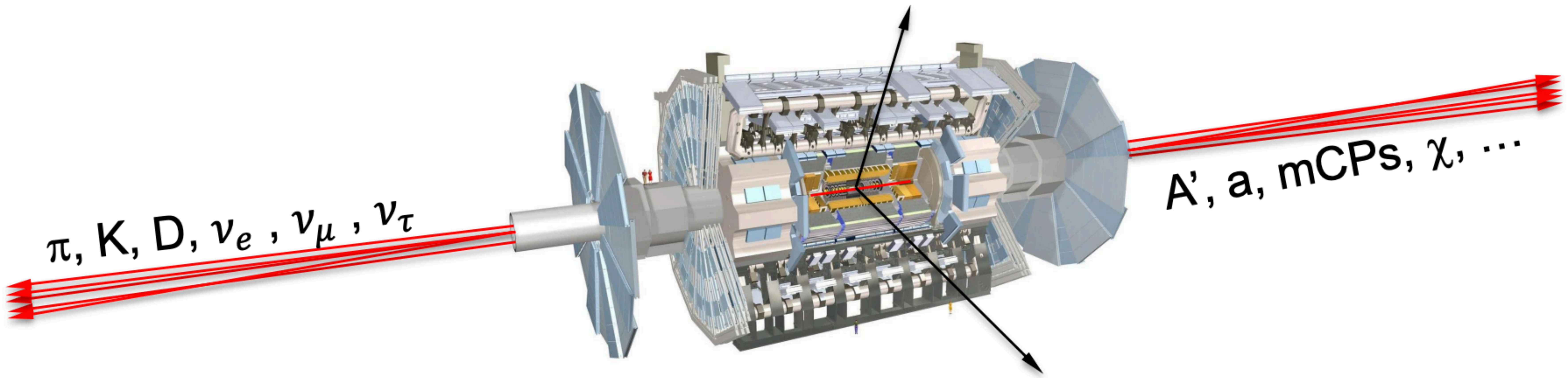
Overview

- Introduction
- Facility Status Overview
- Proposed Experiments (short!)
- Synergies with Astroparticle Physics
  - Light Hadron Production
  - Prompt Neutrino Production
  - (Dark Matter Searches)
- Summary & Conclusions



Introduction

- Question: What opportunities are we currently missing from a lack of coverage of far-forward physics at the LHC?



- By far the largest flux of energetic light particles is in the far-forward direction (mesons, neutrinos, and maybe also dark photons, ALPs, mCPs, DM, …)
- Proposal: Forward Physics Facility (FPF) at LHC in ATLAS line-of-sight ($\eta \gtrsim 7$)
- Large synergies between FPF physics and astroparticle physics!

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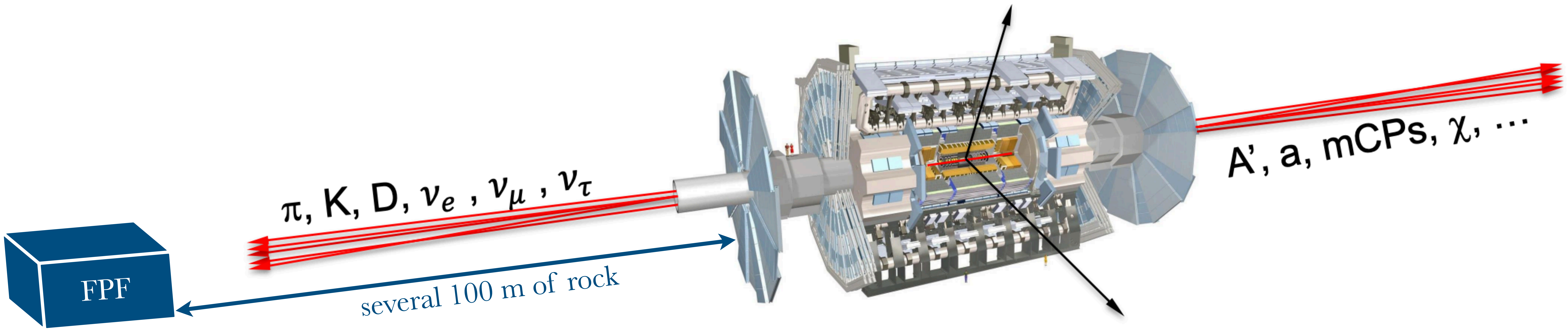

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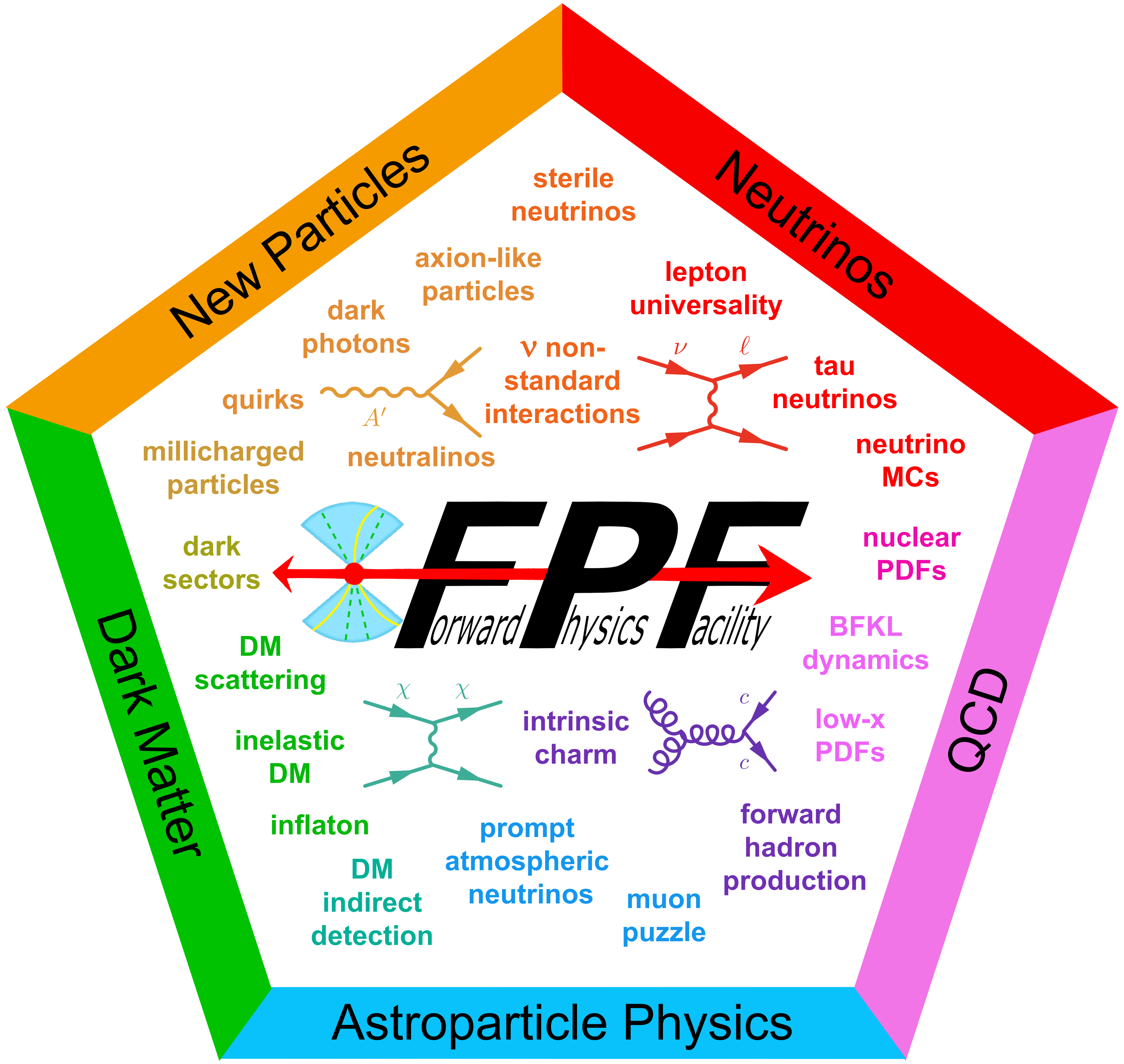
Disclaimer

- Large (multi-)community effort
- Comprehensive physics program
  - Long-lived particles
  - Dark Matter and BSM scattering
  - Quantum Chromodynamics
  - Neutrino physics
  - Astroparticle physics



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- Large (multi-)community effort
- Comprehensive physics program
  - Long-lived particles
  - Dark Matter and BSM scattering
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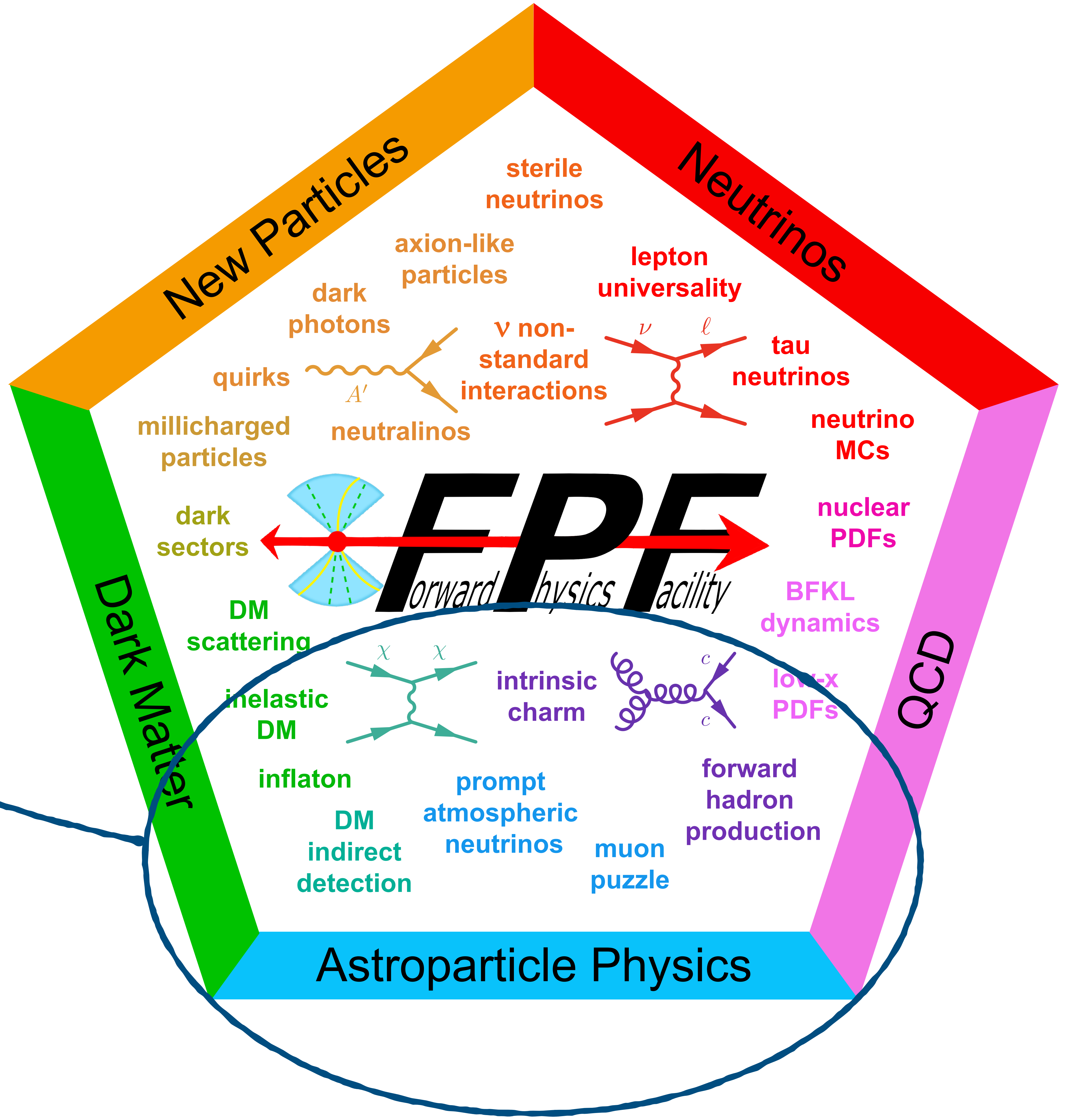
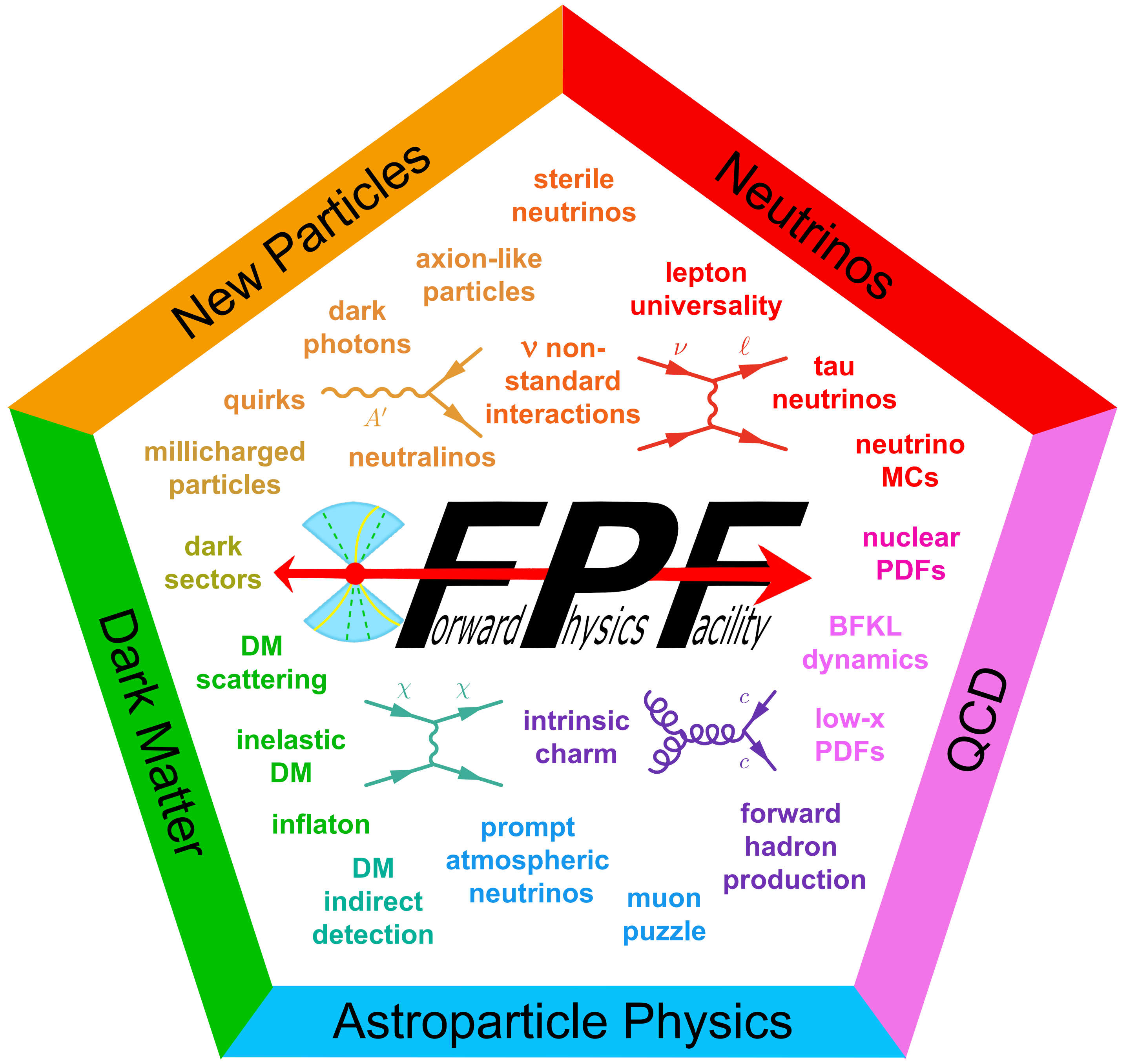
  - Neutrino physics
  - Astroparticle physics
- This talk's focus:
  - The facility & organization
  - Astroparticle physics

This talk



FPF Progress

- Previous FPF Meetings:
  - FPF Kickoff Meeting, November 9-10, 2020
  - FPF2 Meeting, May 27-28, 2021
  - FPF3 Meeting, October 25-26, 2021
  - FPF4 Meeting, January 31-February 1, 2022
  - FPF5 Meeting, November 15-16, 2022
- Next:
  - FPF6 Meeting, June 8-9, 2023
- Snowmass 2021 Process:
  - Meetings embedded in Snowmass 2021 process
  - Snowmass LoIs, "Short Paper", White Paper



FPF Short Paper

- Further reading:
  - First "real" paper on the FPF
  - About 80 authors
  - About 75 pages
  - First collection of ideas
  - Reference for future work
  - Published in Physics Reports 968 (2022)
  - Pre-print: arXiv:2109.10905
  - Basis for Snowmass White Paper…

BNL-222142-2021-FORE, CERN-PBC-Notes-2021-025, DESY-21-142, FERMILAB-CONF-21-452-AE-E-ND-PPD-T
KYUSHU-RCAPP-2021-01, LU TP 21-36, PITT-PACC-2118, SMU-HEP-21-10, UCI-TR-2021-22

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

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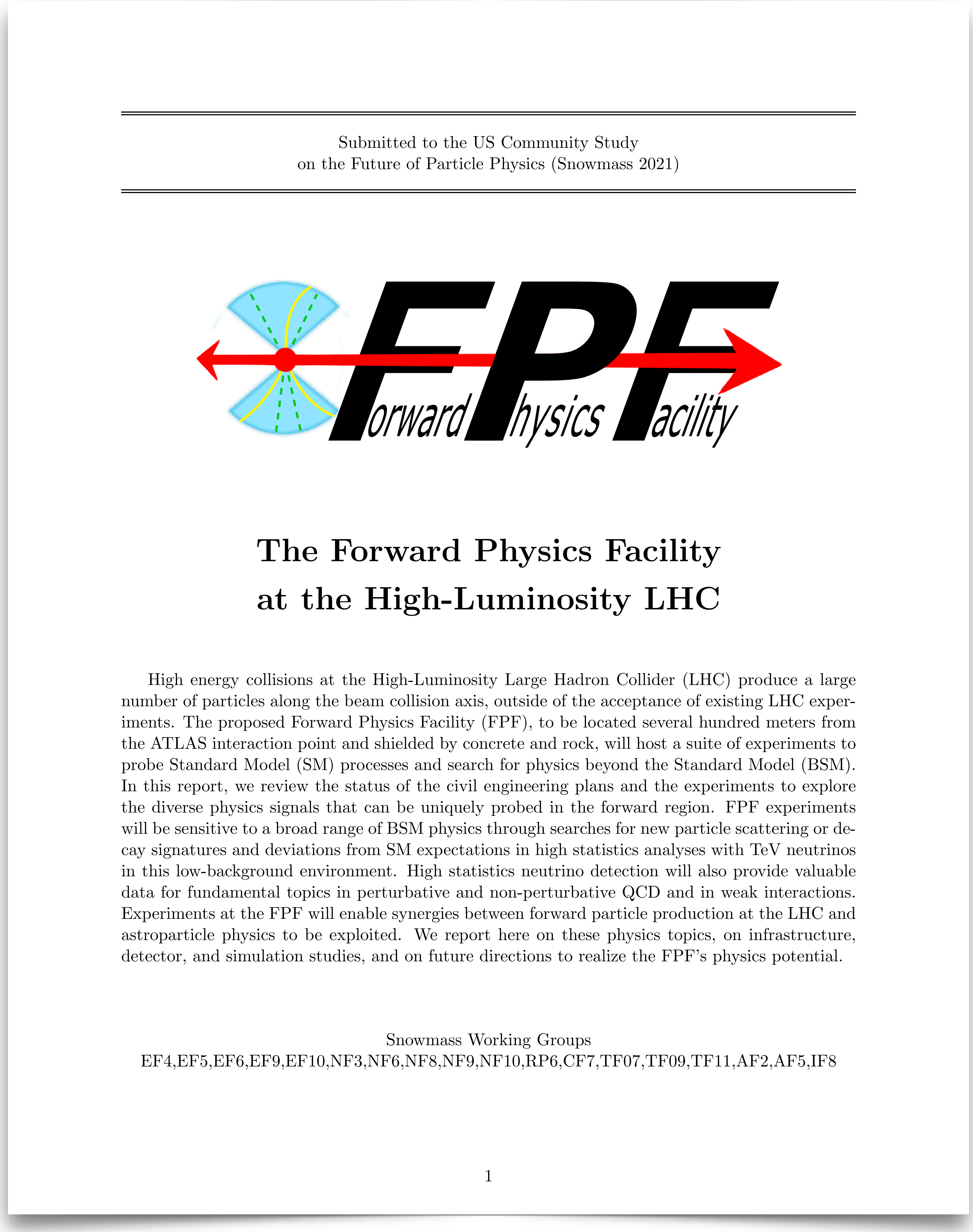
The Forward Physics Facility (FPF) is a proposal to create a cavern with the space and infrastructure to support a suite of far-forward experiments at the Large Hadron Collider during the High Luminosity era. Located along the beam collision axis and shielded from the interaction point by at least 100 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 and the experiments currently envisioned to realize the FPF's physics potential. We then review 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.

Snowmass White Paper

- <u>Even further reading:</u>
  - Comprehensive 429-page document
  - More than 230 authors
  - More than 150 endorsers
  - <u>Collection of ideas:</u>
    - The facility
    - Physics topics
    - Experiments
  - J. Phys. G: Nucl. Part. Phys. 50 (2023)
  - Pre-print: arXiv:2203.05090



Submitted to the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Forward Physics Facility

The Forward Physics Facility
at the High-Luminosity LHC

High energy collisions at the High-Luminosity Large Hadron Collider (LHC) produce a large number of particles along the beam collision axis, outside of the acceptance of existing LHC experiments. The proposed Forward Physics Facility (FPF), to be located several hundred meters from the ATLAS interaction point and shielded by concrete and rock, will host a suite of experiments to probe Standard Model (SM) processes and search for physics beyond the Standard Model (BSM). In this report, we review the status of the civil engineering plans and the experiments to explore the diverse physics signals that can be uniquely probed in the forward region. FPF experiments will be sensitive to a broad range of BSM physics through searches for new particle scattering or decay signatures and deviations from SM expectations in high statistics analyses with TeV neutrinos in this low-background environment. High statistics neutrino detection will also provide valuable data for fundamental topics in perturbative and non-perturbative QCD and in weak interactions. Experiments at the FPF will enable synergies between forward particle production at the LHC and astroparticle physics to be exploited. We report here on these physics topics, on infrastructure, detector, and simulation studies, and on future directions to realize the FPF's physics potential.

Snowmass Working Groups
EF4,EF5,EF6,EF9,EF10,NF3,NF6,NF8,NF9,NF10,RP6,CF7,TF07,TF09,TF11,AF2,AF5,IF8

1

Snowmass White Paper

FPF
Forward Physics Facility

- Comprehensive list of contents:

Contents

This Talk

FPF Status

- Snowmass process:
  - From the energy frontier executive summary:

> "Our highest immediate priority accelerator and project ist the HL-LHC, the successful completion of the detector upgrades, operations of the detectors at the HL-LHC, data taking and analysis, including the construction of auxiliary experiments that extend the reach of HL-LHC in kinematic regions uncovered by the detector upgrades."

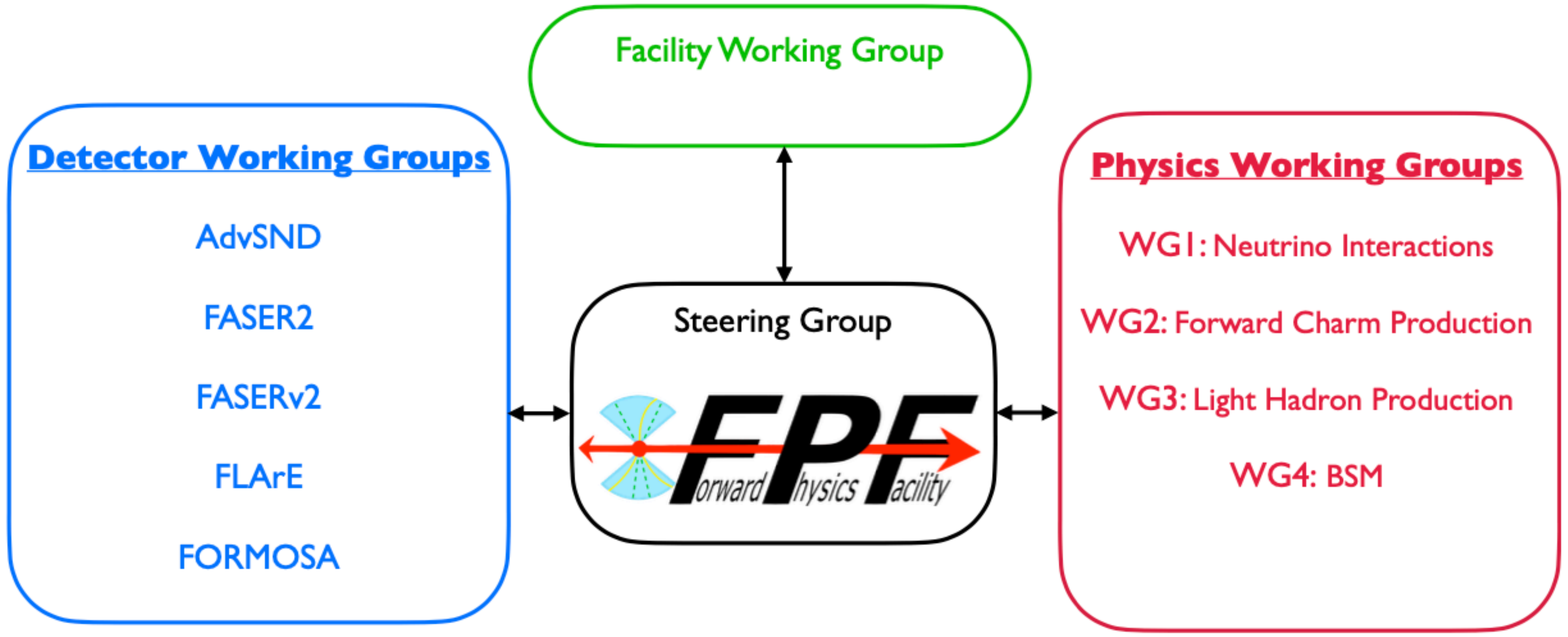
  - Also strong endorsements from neutrino, rare processes, and cosmic frontiers!
  - There now appears to be wide acceptance that the physics case is strong!
  - We now have to move toward CDRs for the facility and the experiments
  - Very positive P5 Snowmass report, including budget constraints and recommendations to the DOE and NSF…

FPF Status

- News from CERN:
  - First meeting with CERN directorate (Gianotti, Mnich, Lamont) in June 2022
  - Some action items identified:
    - We should move to the next stage of organizational infrastructure, e.g. webpage with contact names, Slack channels, twikis, etc. ✓
    - We should contact the LHCC about submitting an EOI ✓
    - We need stronger commitments from leading experimental groups to work on FPF experiments
    - The directorate asked to meet with us again around May 2023

FPF Organization

- For the upcoming reviews and CDRs strong physics cases are essential, in particular, <u>more quantitative results are needed!</u>
- <u>Working group (WG) structures:</u>
  - 1 facility WG & 4 physics WGs
  - 5 detector WGs (each experiment)
- FPF Slack workspace for communication
- FPF webpage in preparation…



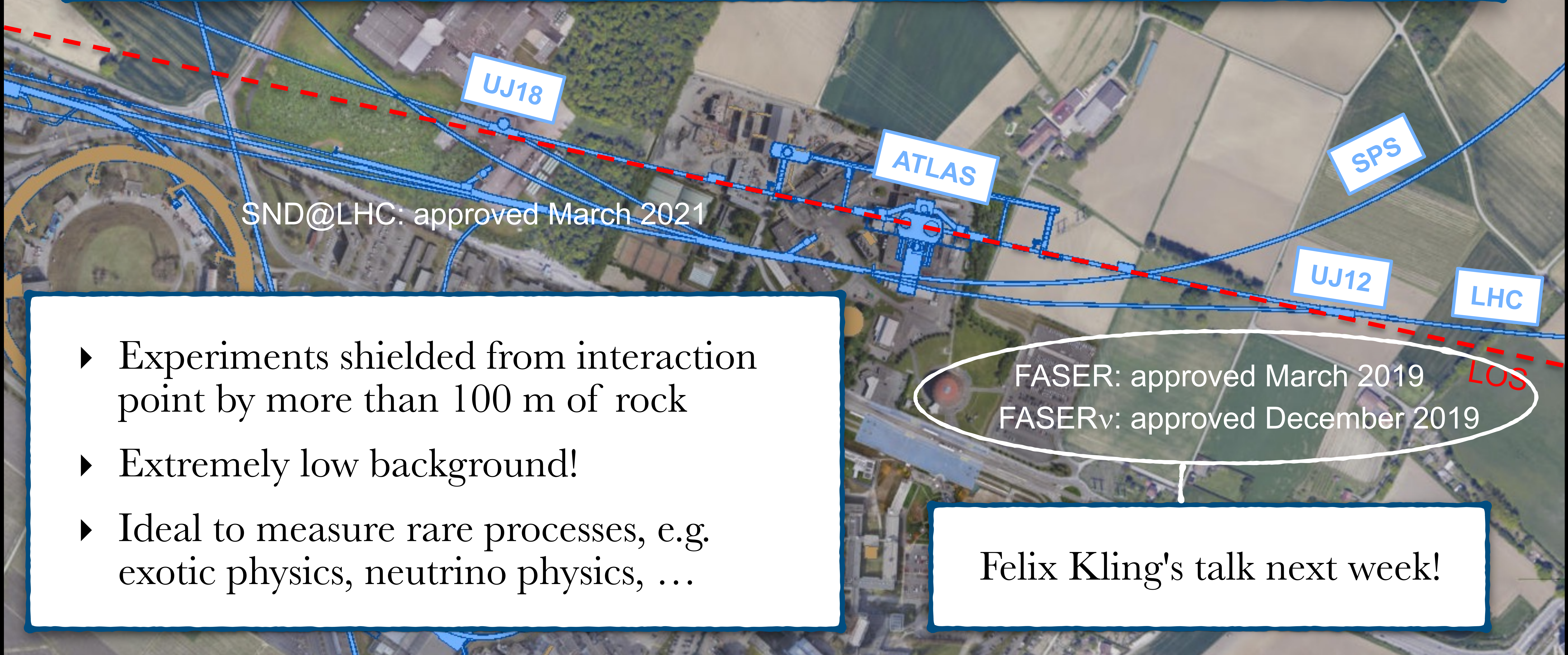
FPF Working Groups										
	Facility WG	Physics WGs				Detector WGs				
	WG0	WG1	WG2	WG3	WG4	WG5	WG6	WG7	WG8	WG9
Topic	Facility	Neutrino Interactions	Charm Production	Light Hadron Production	BSM Physics	FASER2	FASERnu2	FLArE	AdvSND	FORMOSA
Contacts	J. Boyd	J. Rojo	M. H. Reno	D. Soldin, L. Anchordoqui	B. Batell, S. Trojanowski	J. McFayden	A. Ariga, T. Arika	J. Bian, M. Diwan	G. De Lellis	M. Citron, C. Hill

<u>Steering committee:</u> J. Boyd, J. Feng, F. Kling

Facility & Timeline

FAR FORWARD EXPERIMENTS AT LHC RUN 3

There are currently 3 detectors in operation to exploit forward physics potential during the LHC Run 3

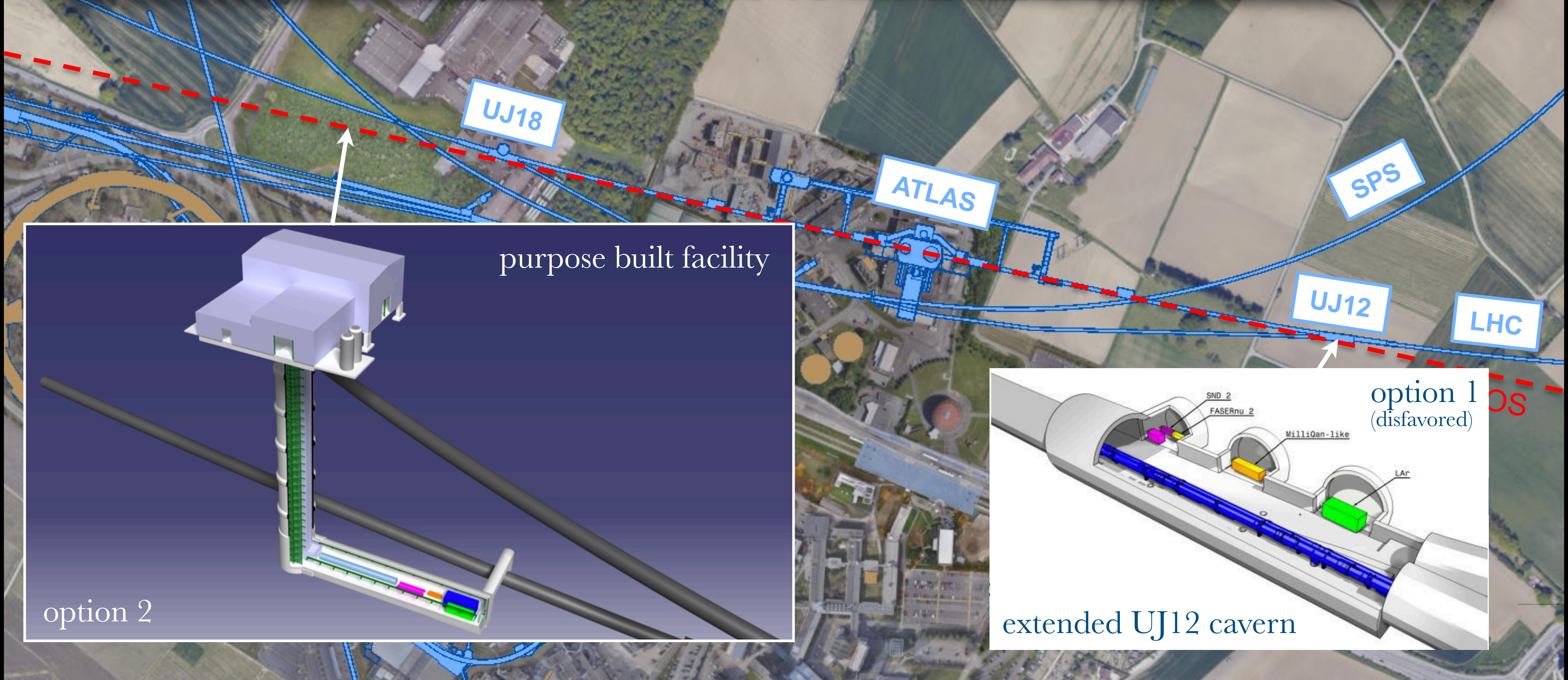


- Experiments shielded from interaction point by more than 100 m of rock
- Extremely low background!
- Ideal to measure rare processes, e.g. exotic physics, neutrino physics, …

Felix Kling's talk next week!

FAR FORWARD EXPERIMENTS AT LHC RUN 3

The FPF is proposed to extend this program into the HL-LHC era!



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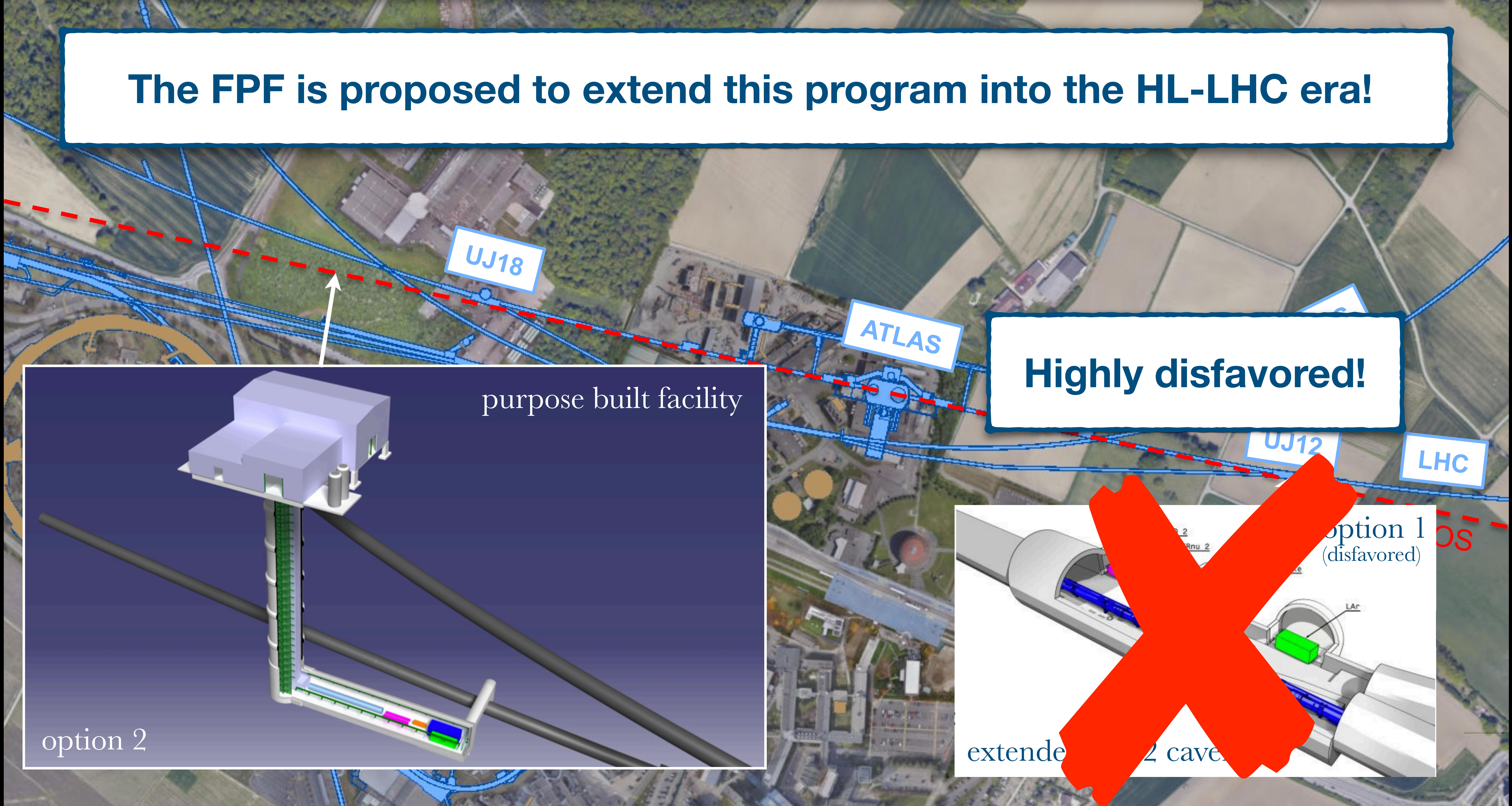
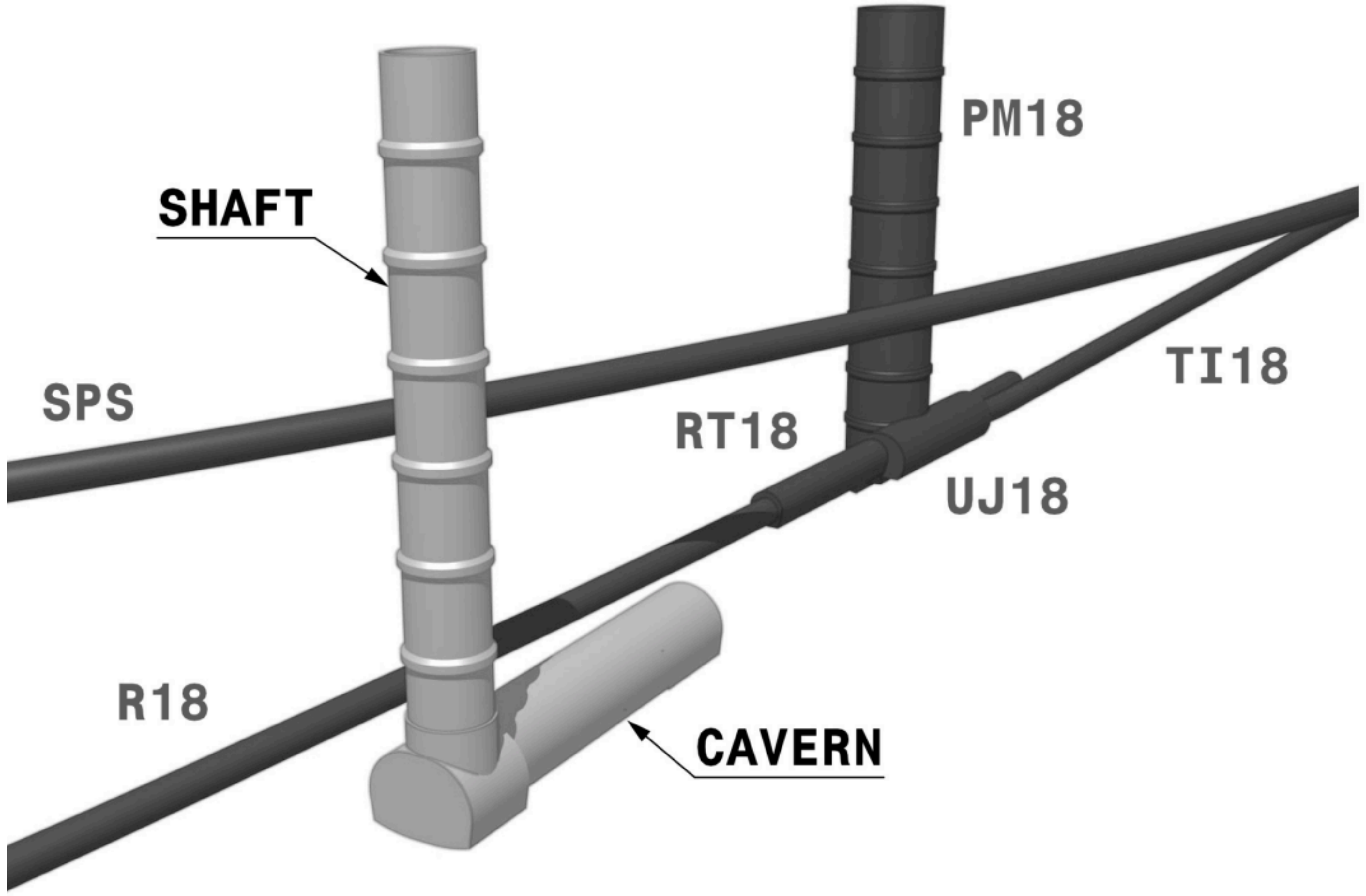
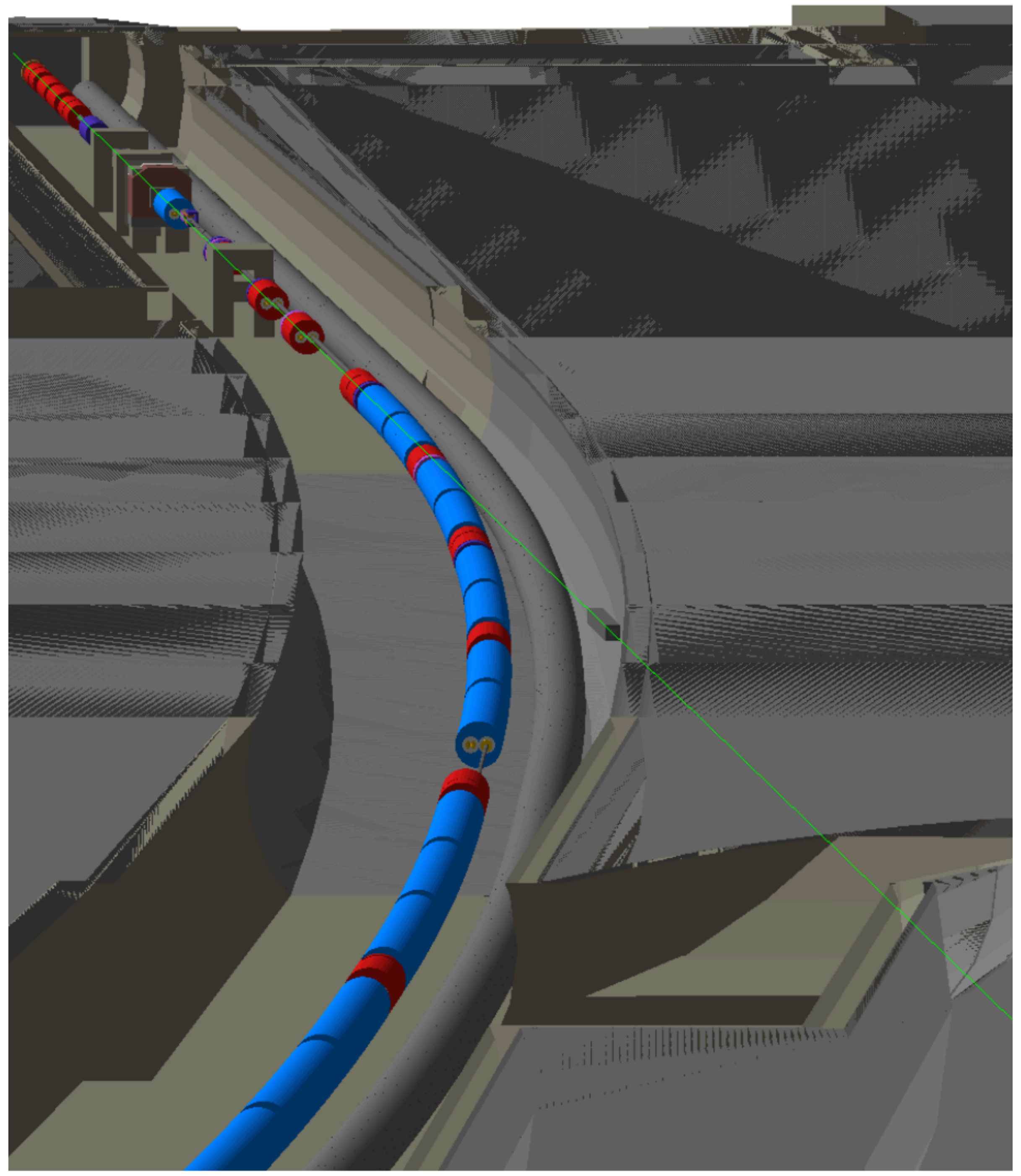
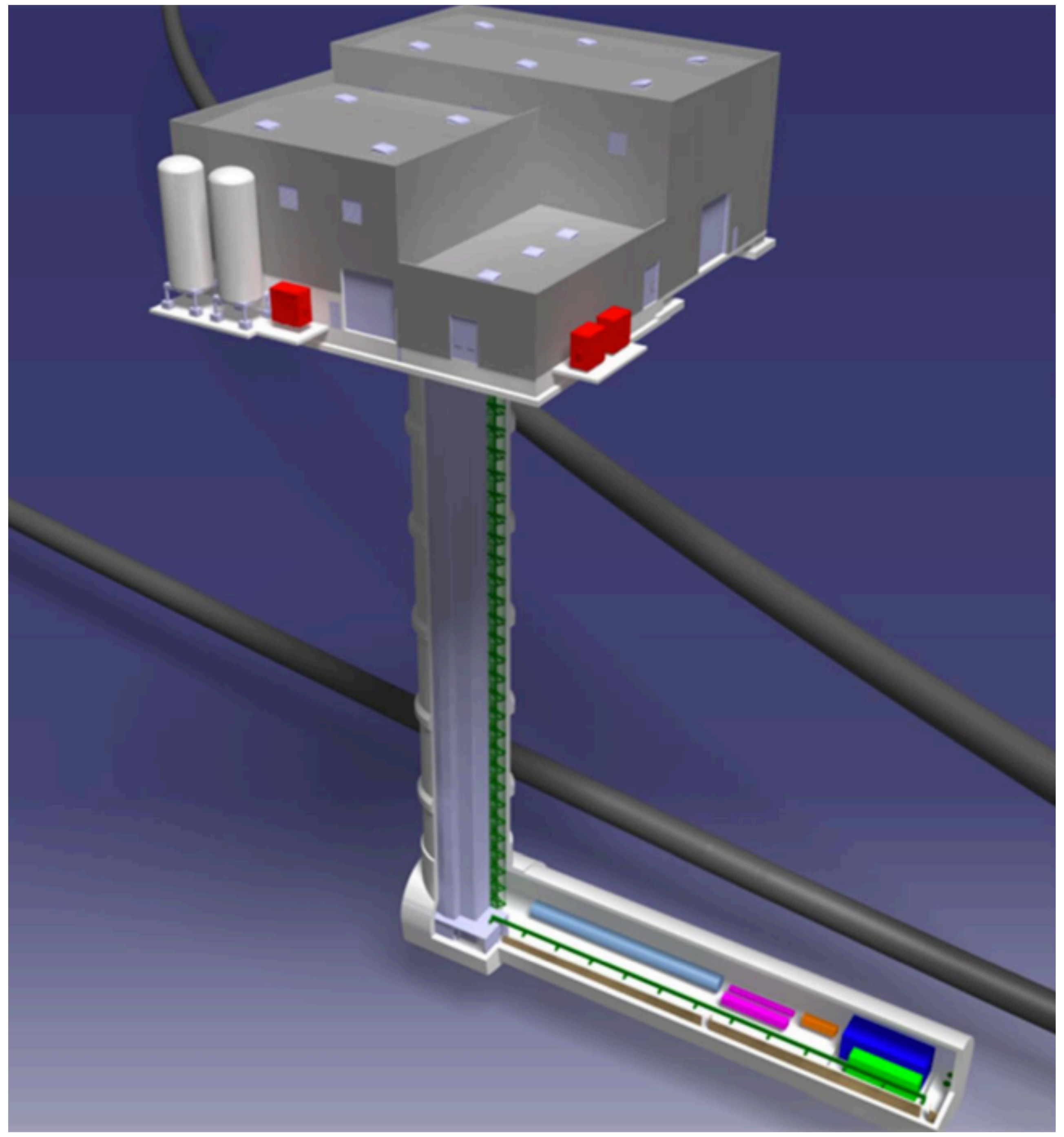


The Facility

- Focus of this talk: <u>purpose built facility</u> (favored option!)
- Extended UJ12 cavern also explored and similar ideas apply (highly disfavored!)
- Currently five proposed experiments (later slides)







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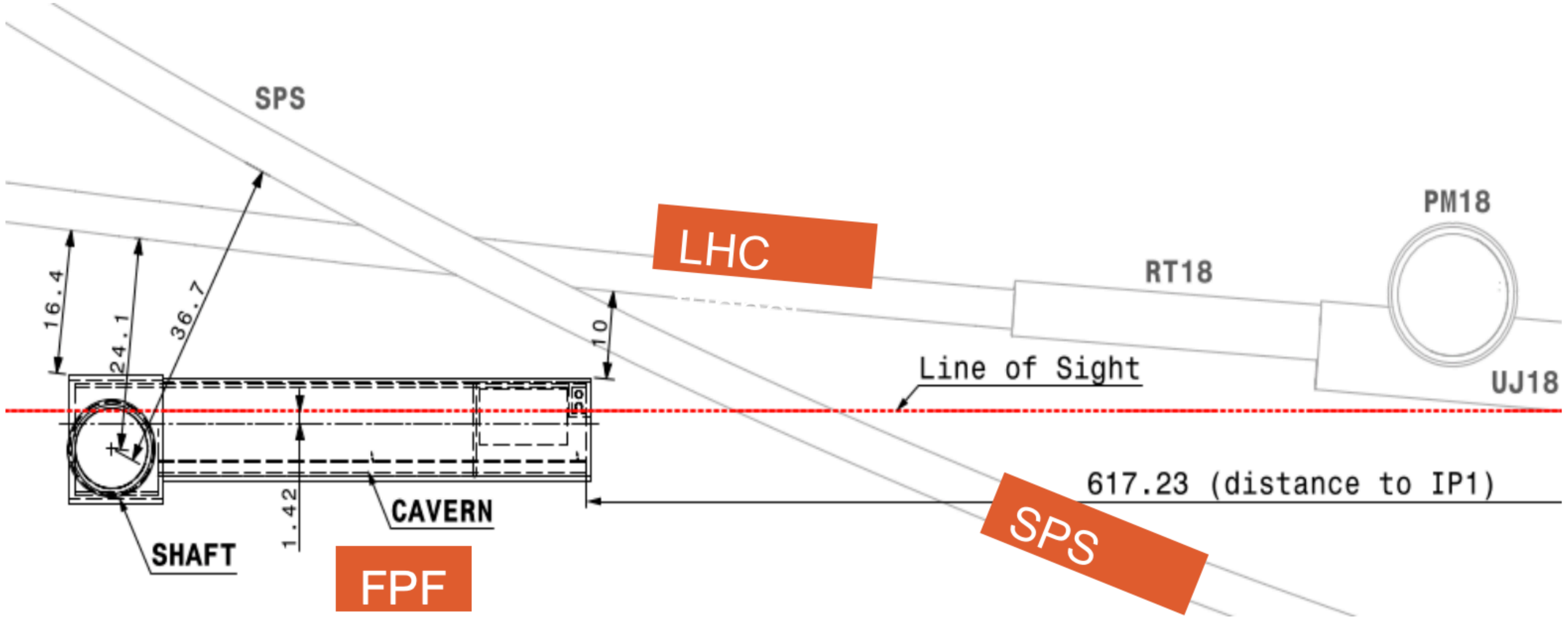

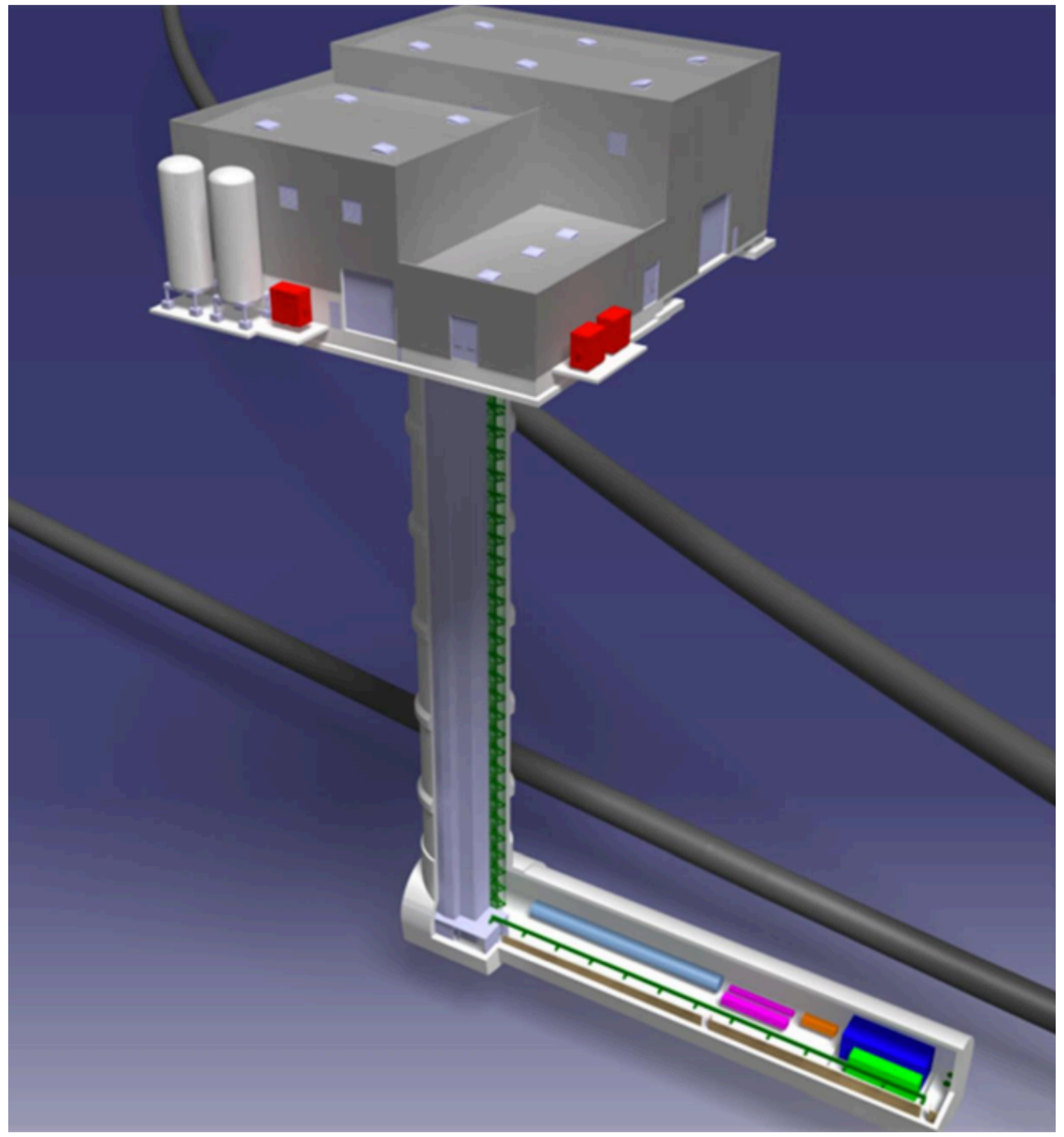

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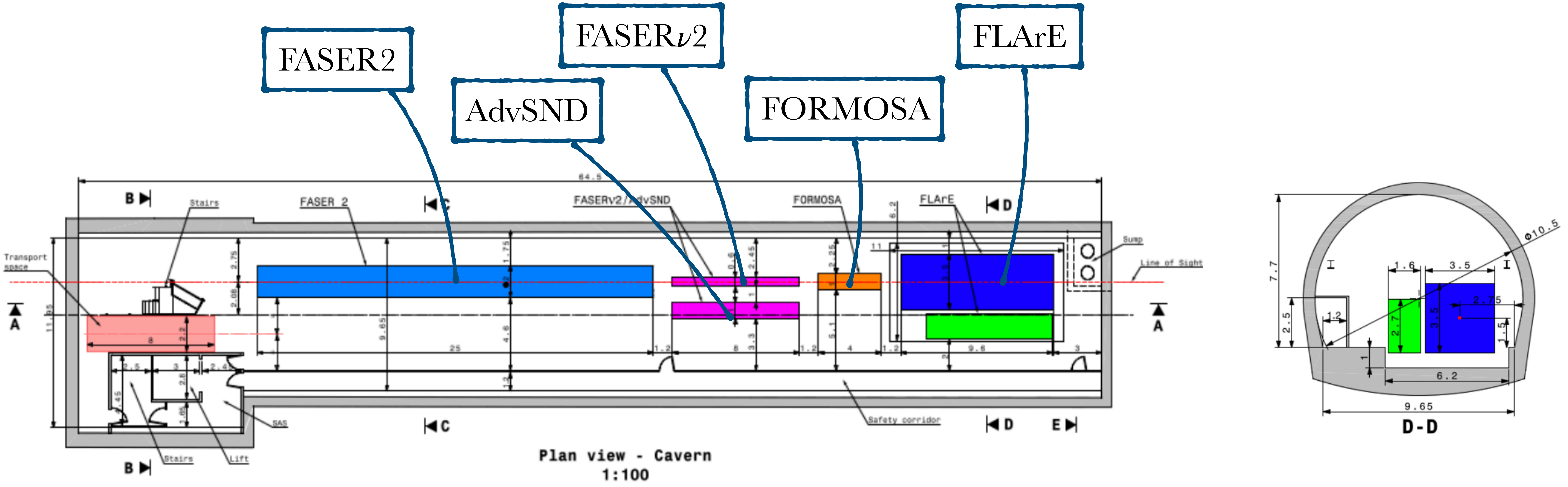
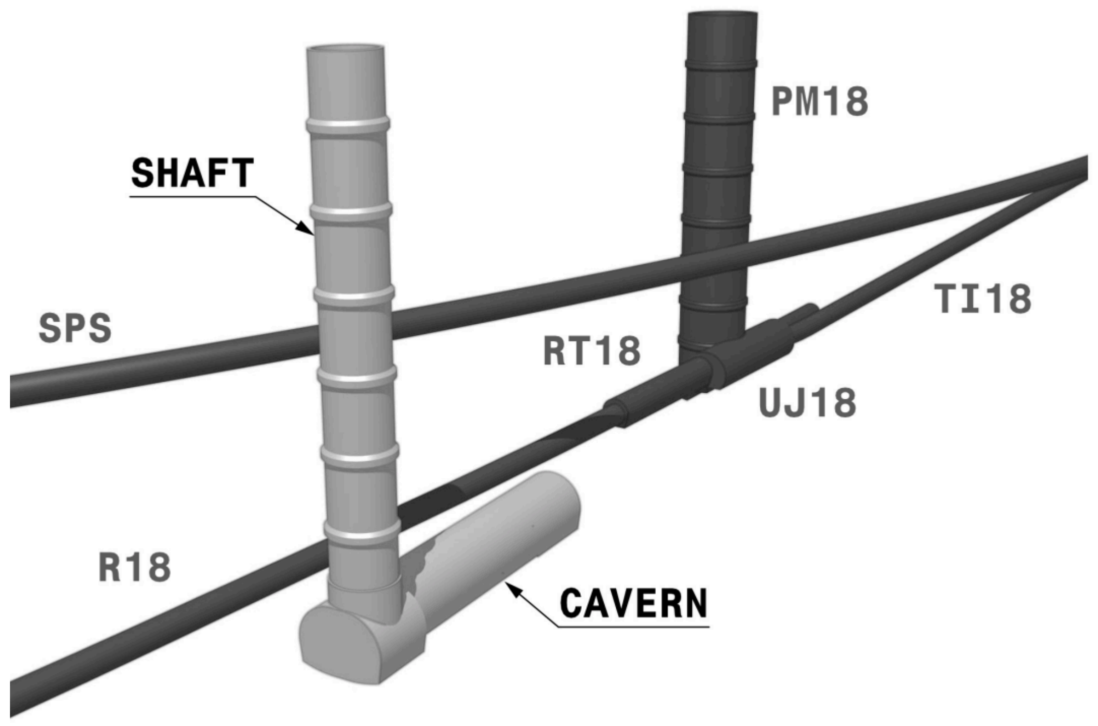
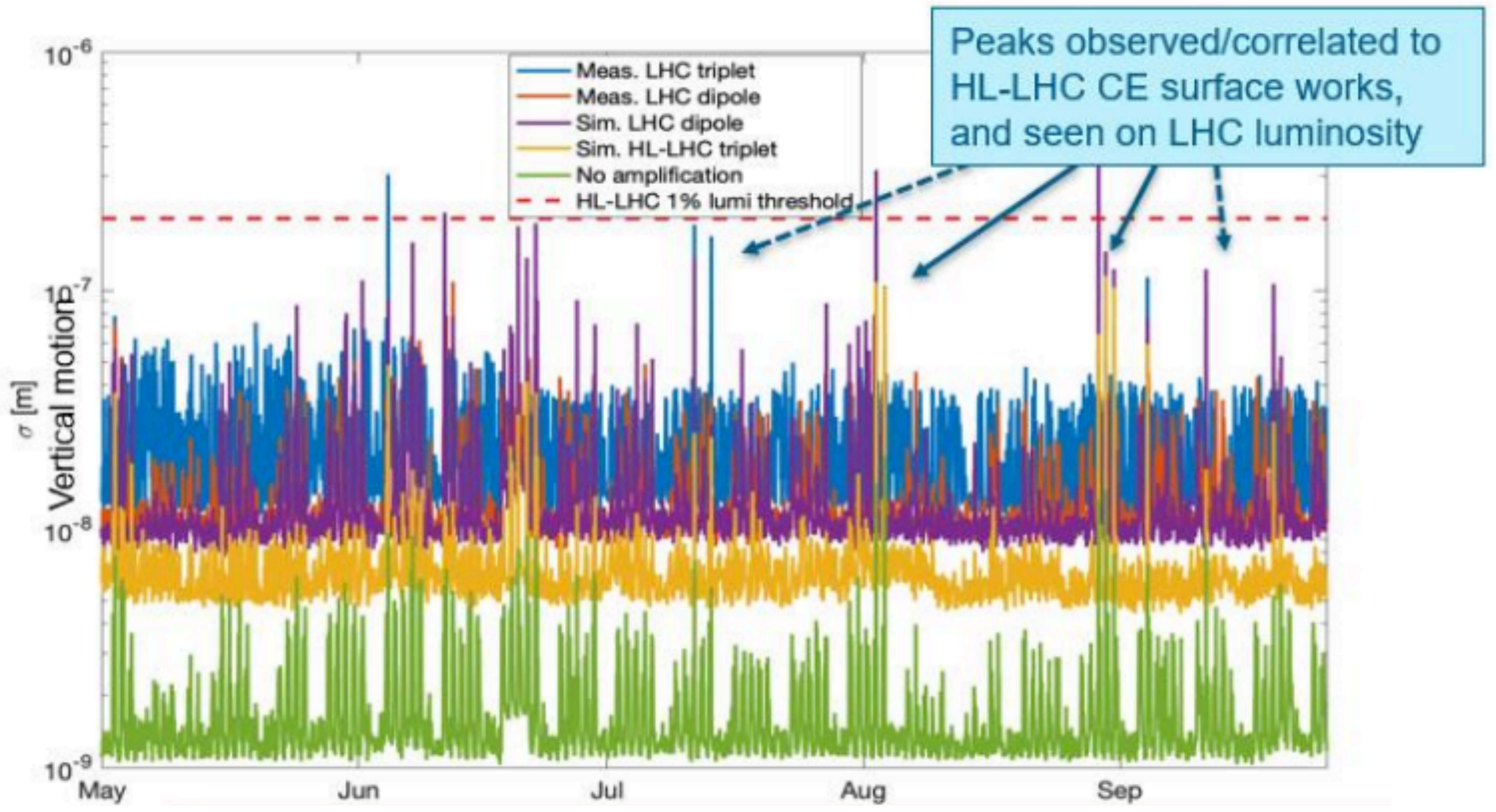


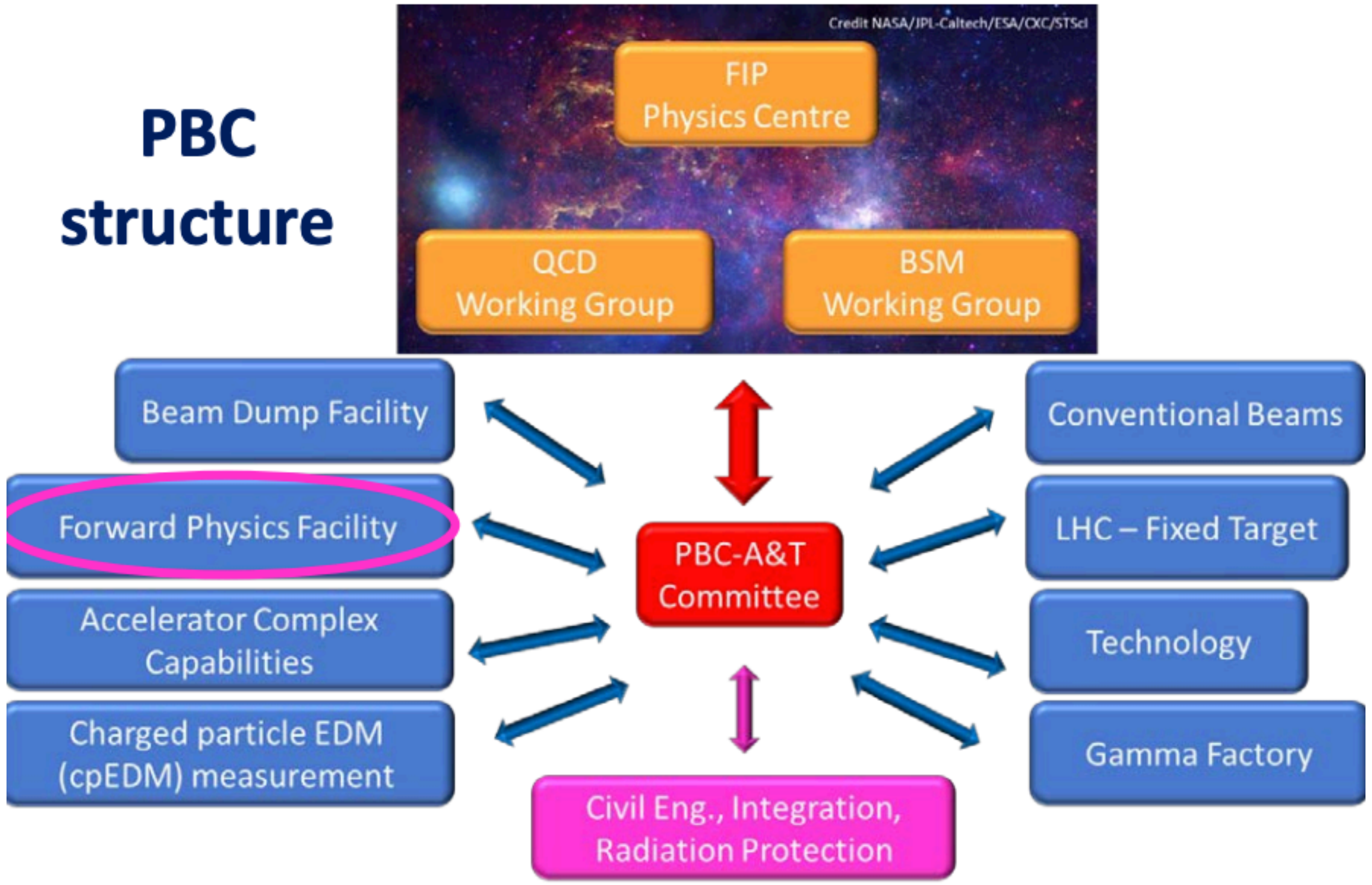
FPF Status

- <u>Latest news from facility / civil engineering:</u>
  - Safety corridor between FPF and LHC tunnel no longer needed
  - Vibration studies indicate that construction of the FPF, installation of services and experiments, will not interfere with LHC operations
  - FPF is one of the major new projects supported by the Physics Beyond Collider (PBC) committee
  - The PBC has allocated 75k CHF for a site investigation study to take a core

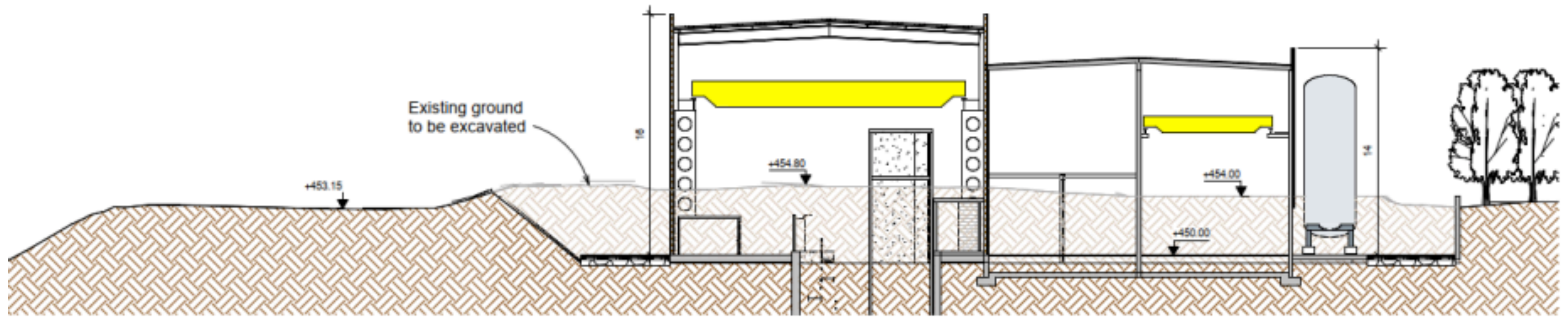




PBC structure



The Facility



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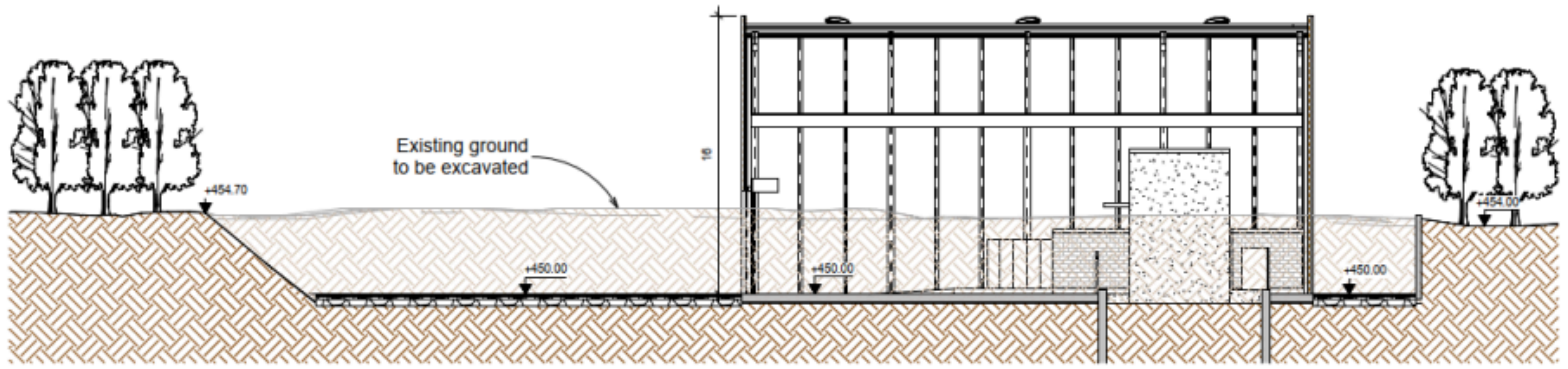

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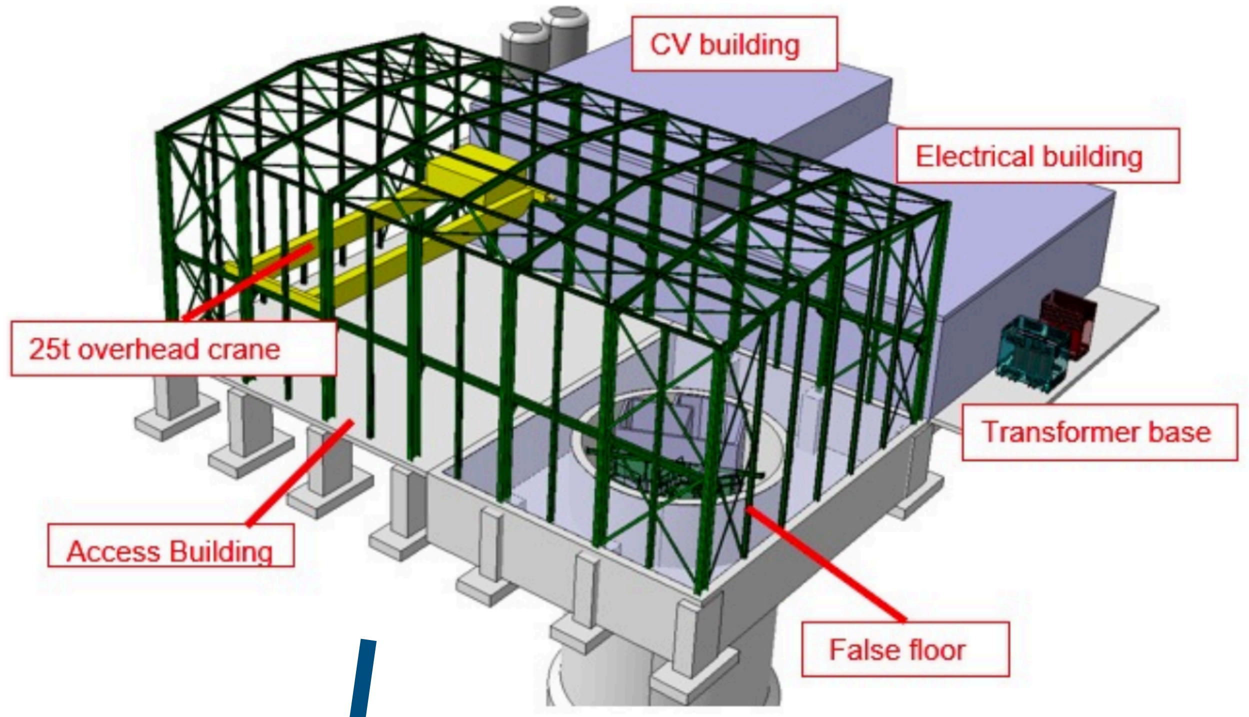

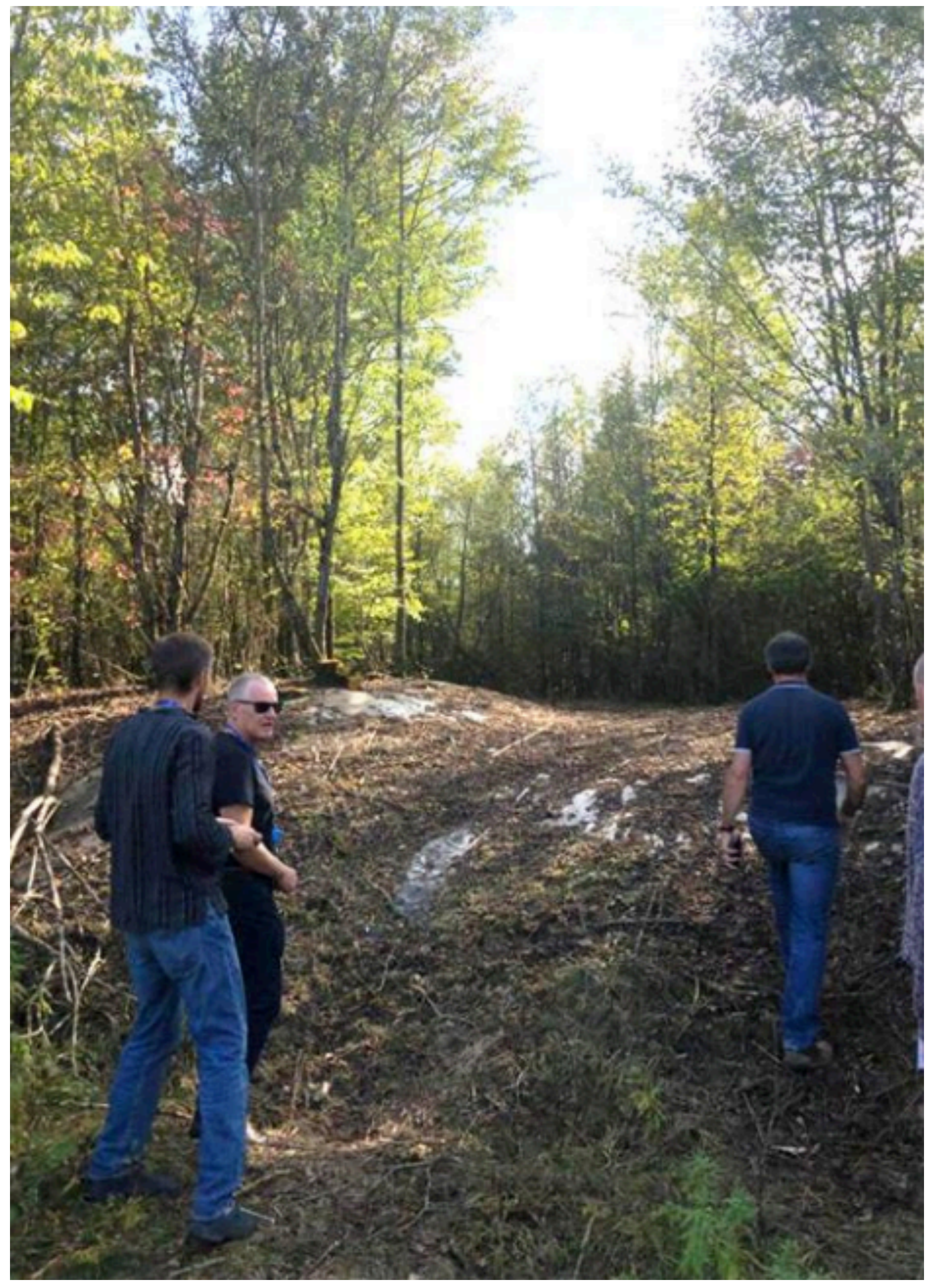

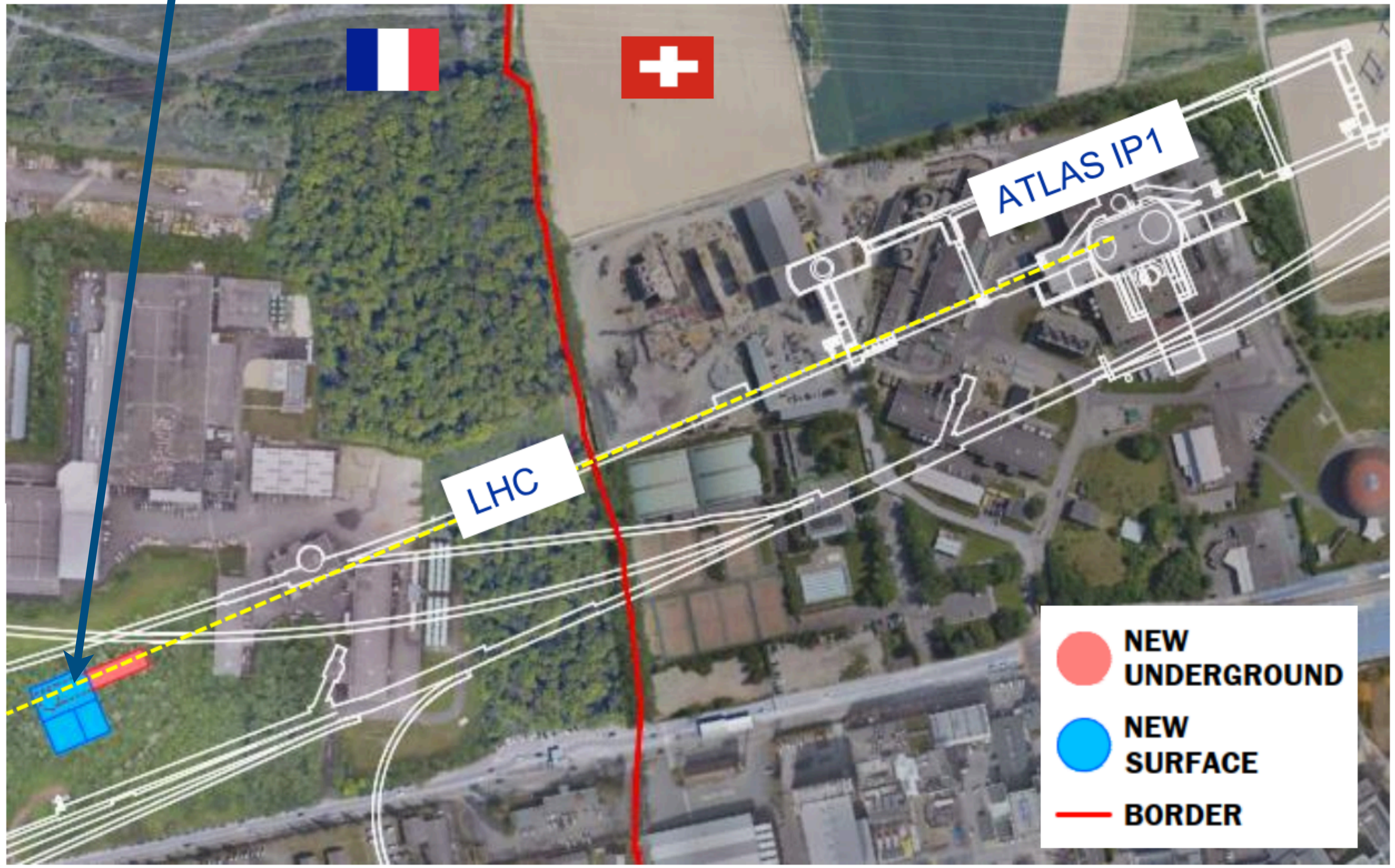

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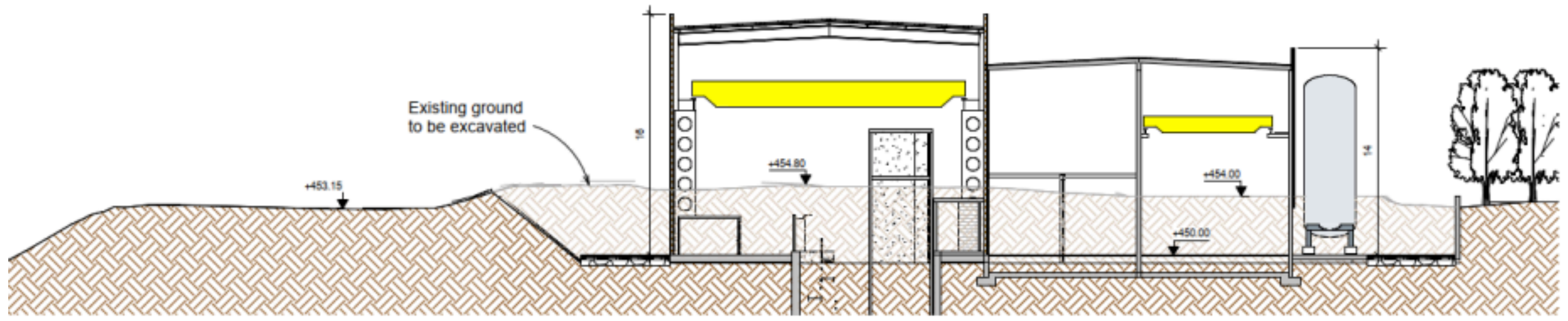

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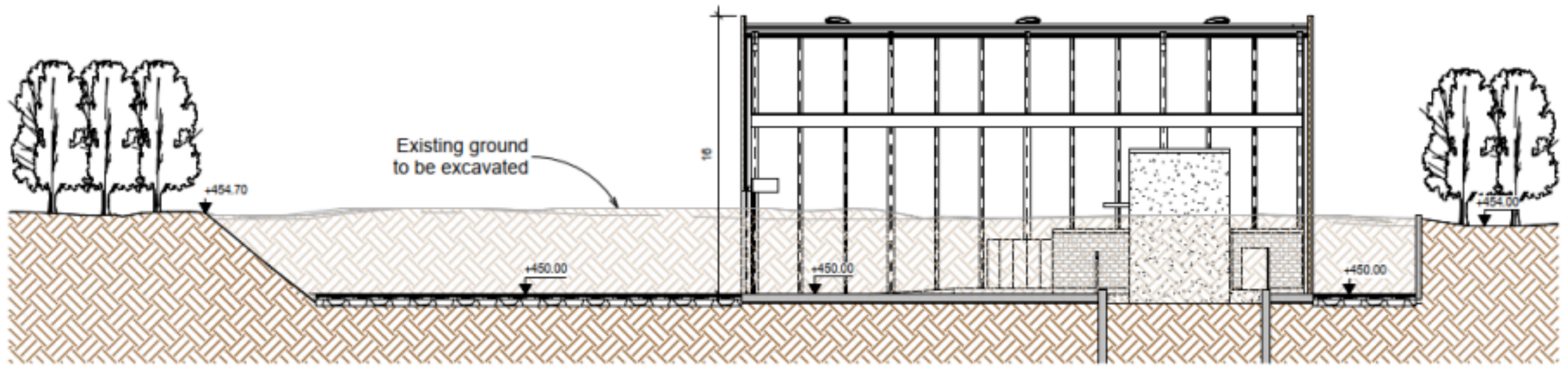

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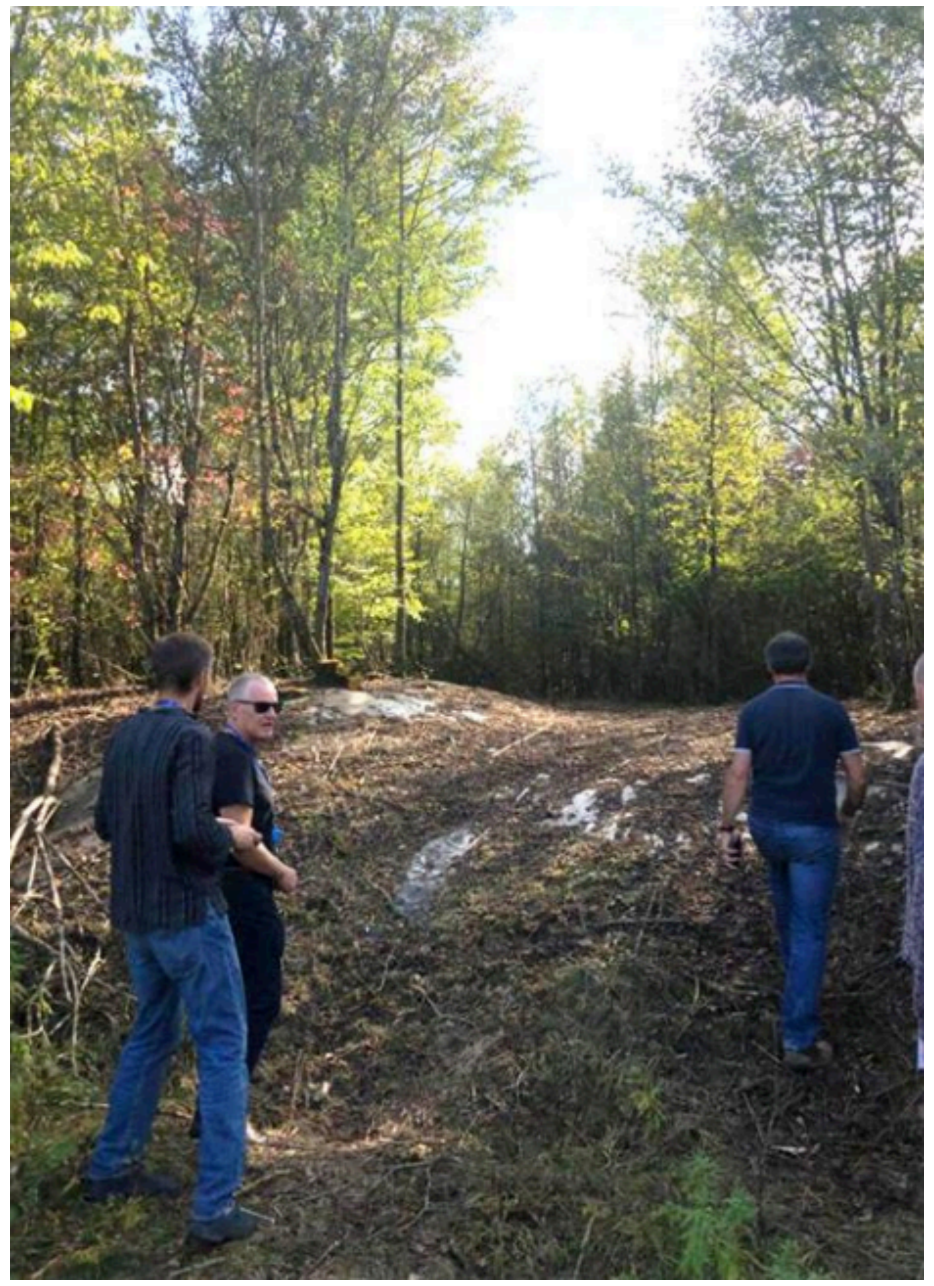

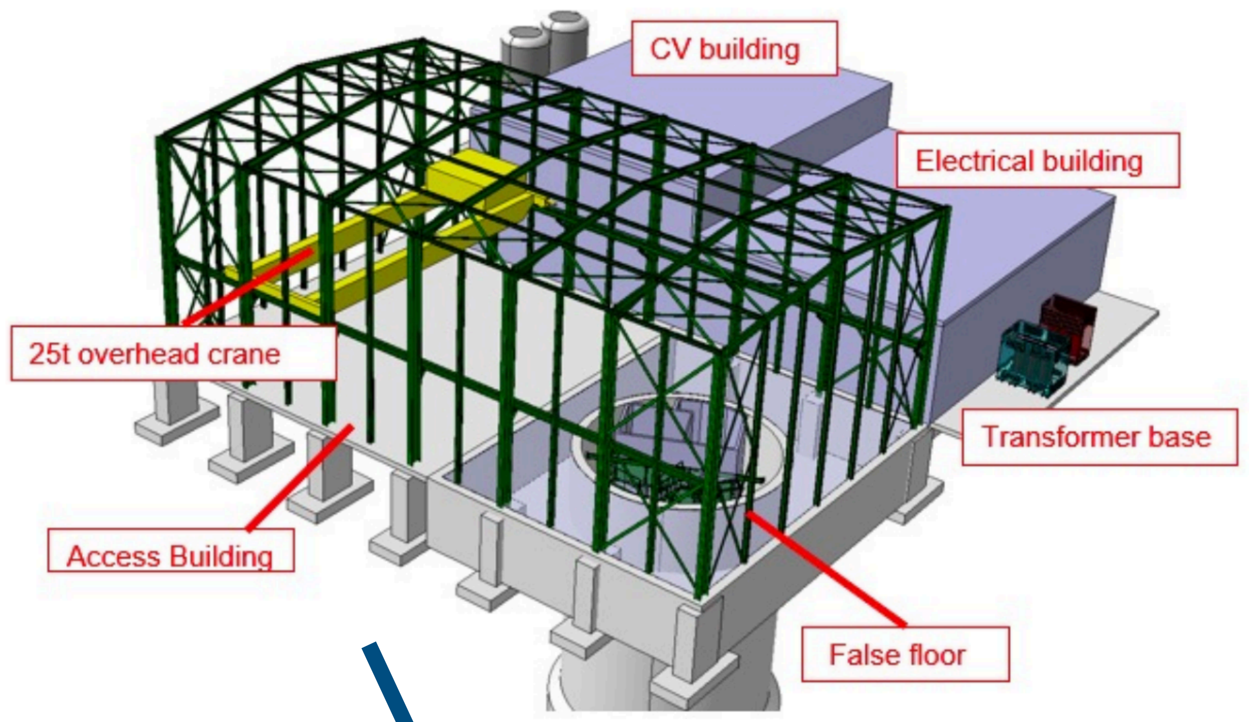

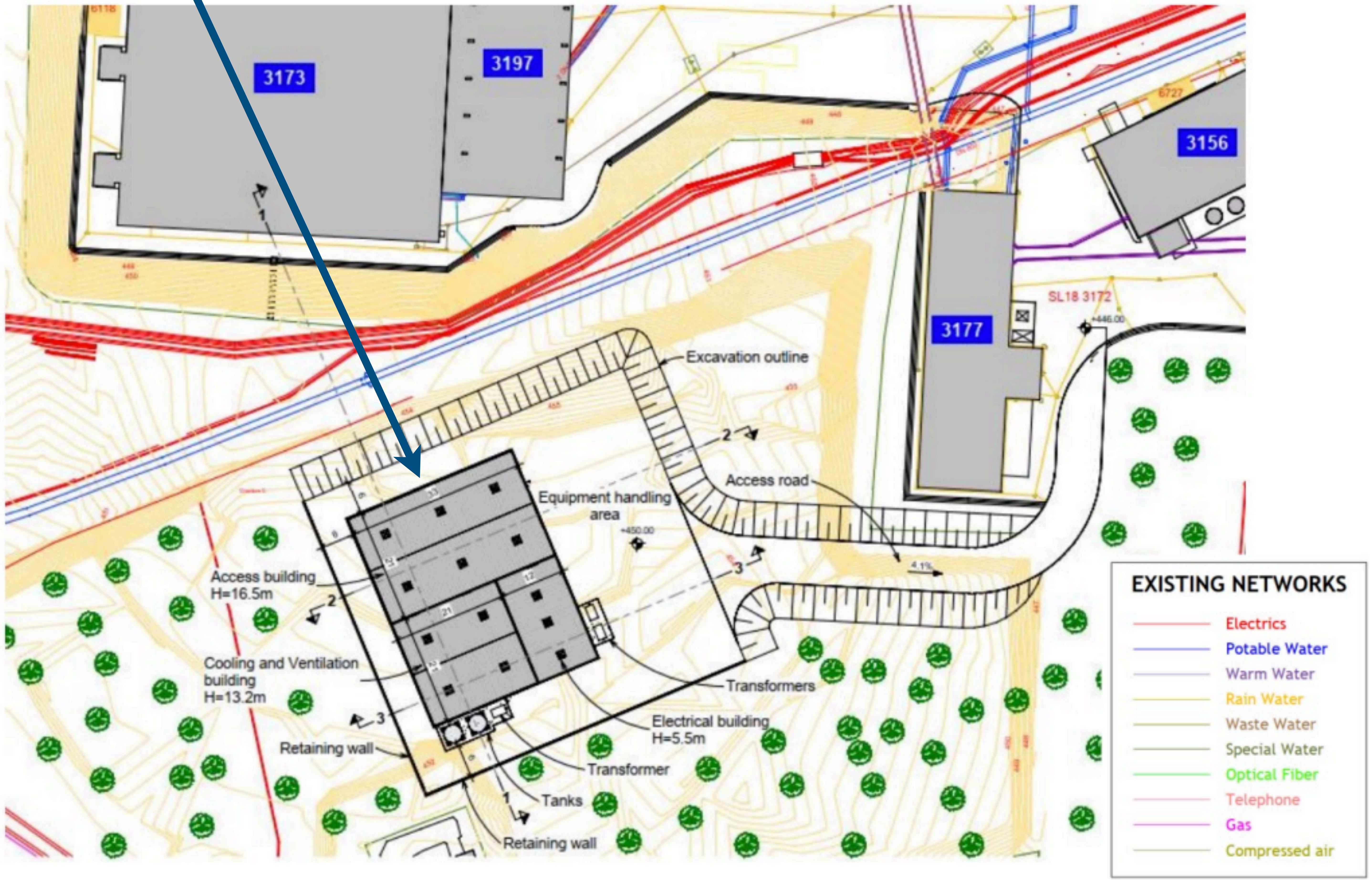

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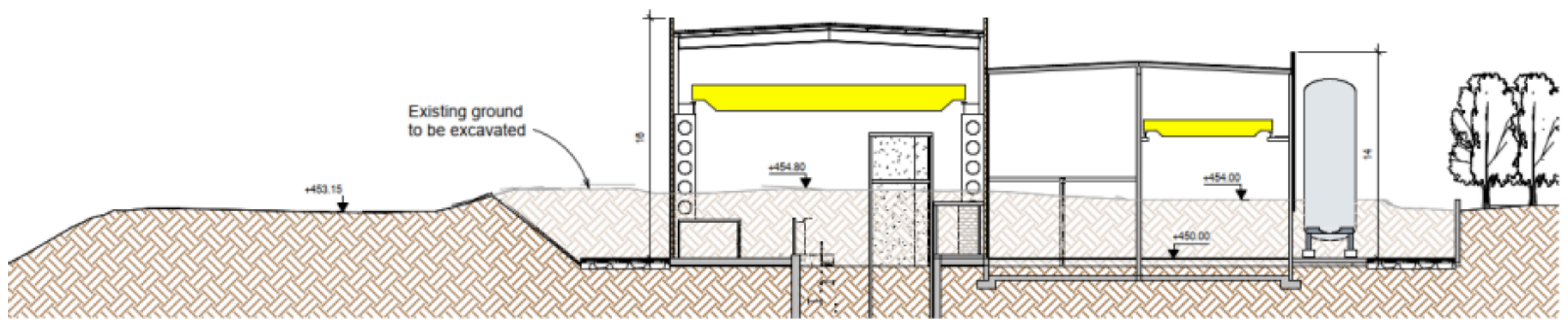
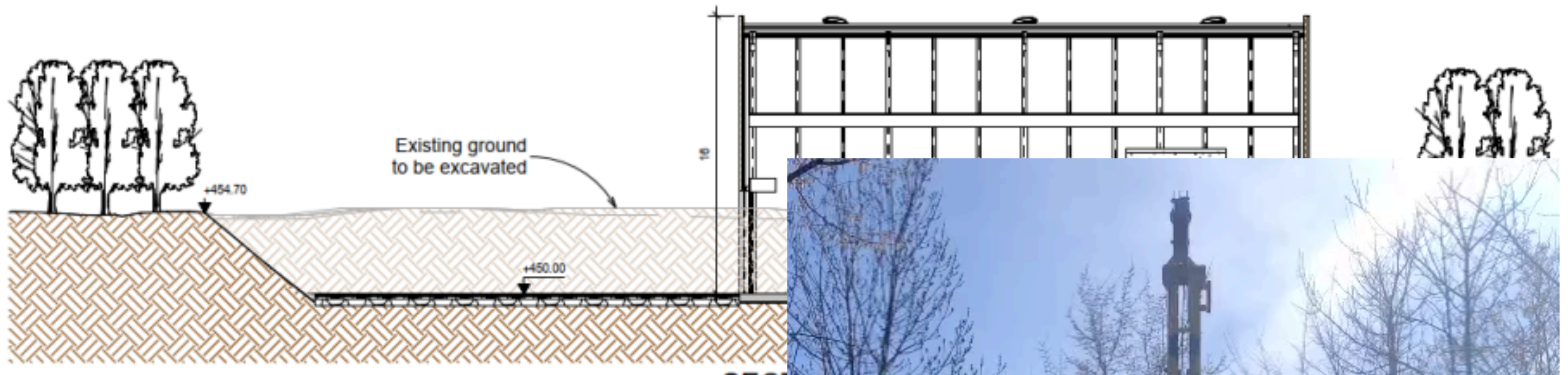
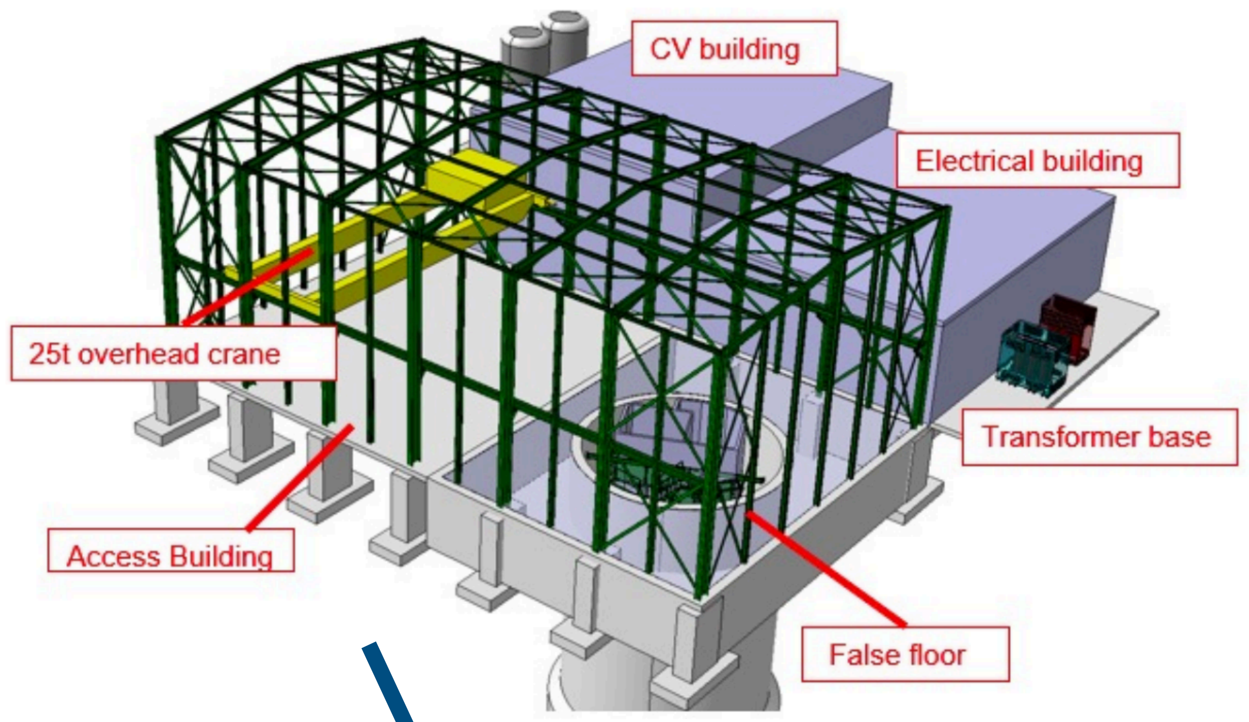
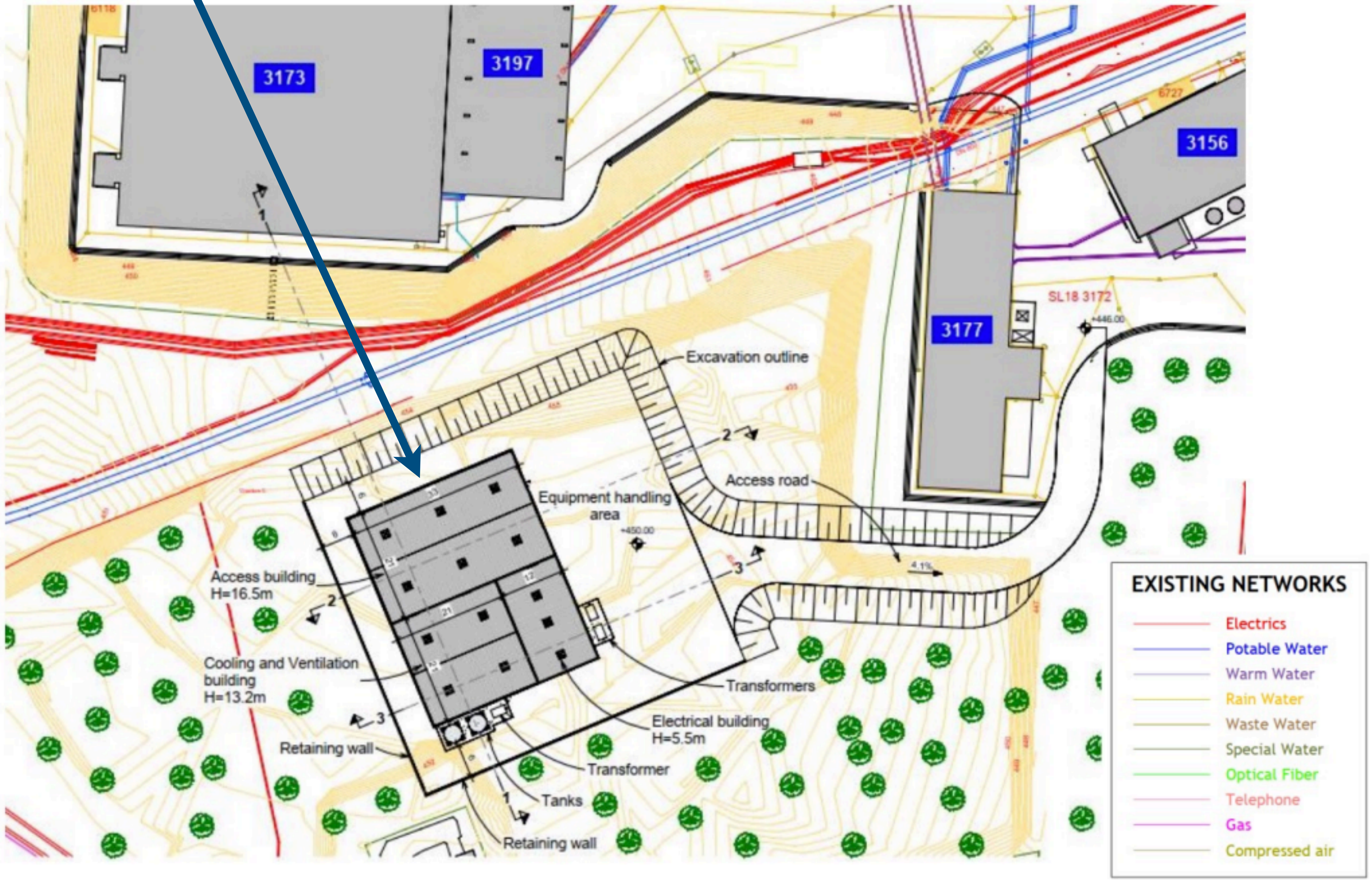
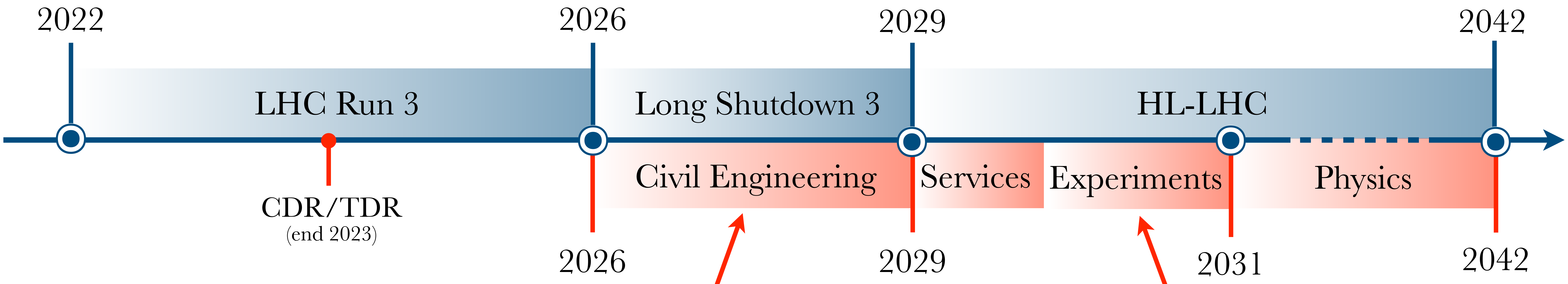


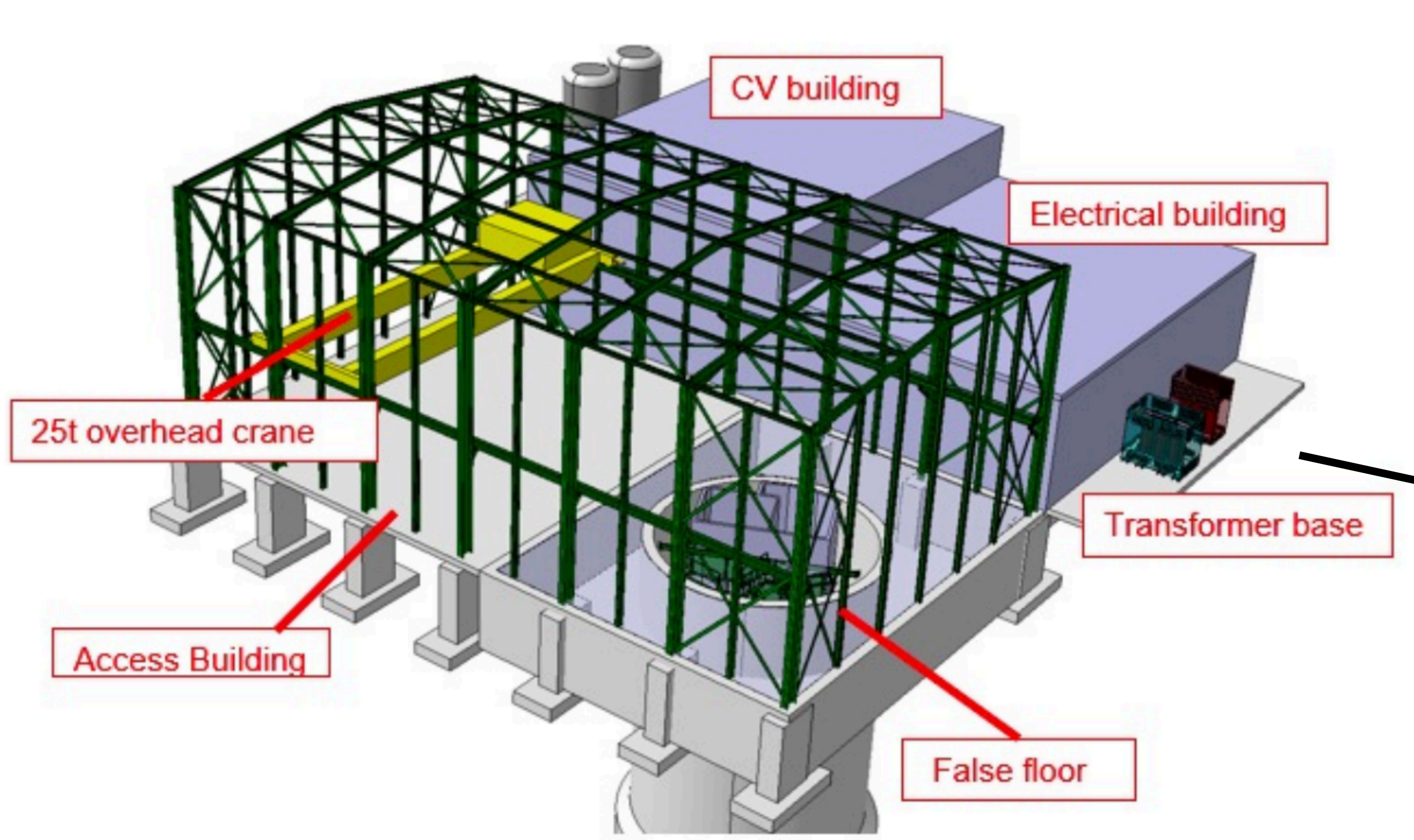


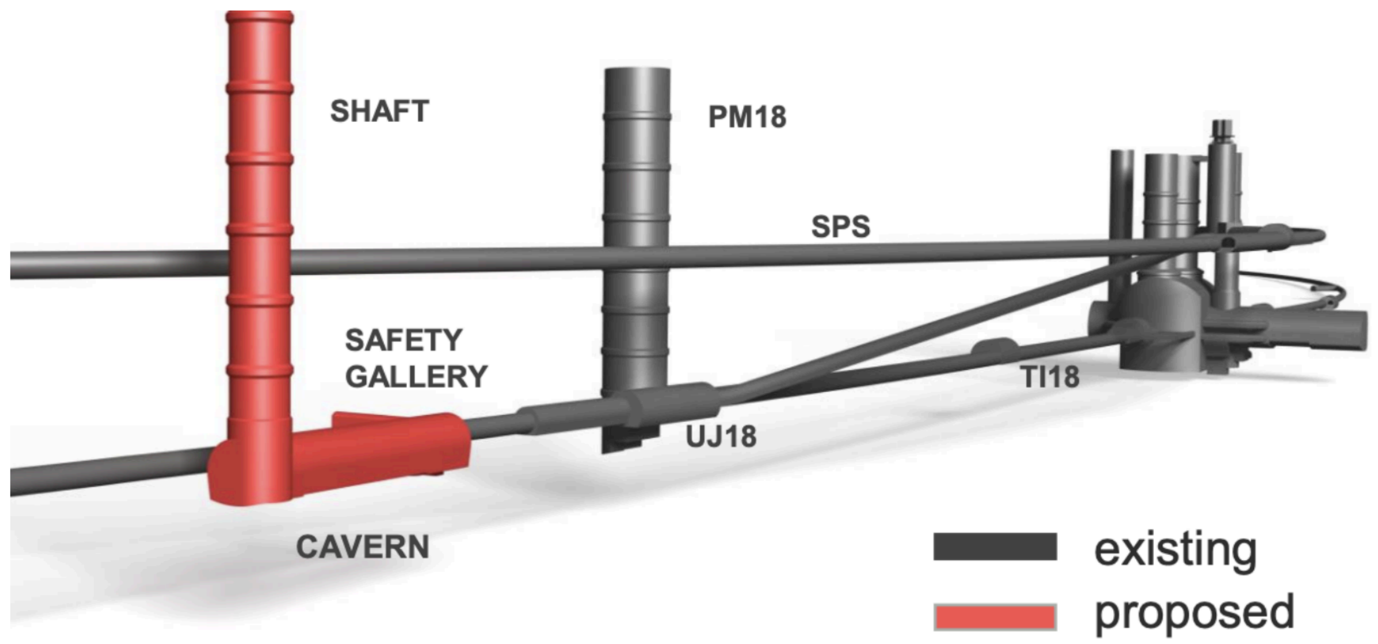


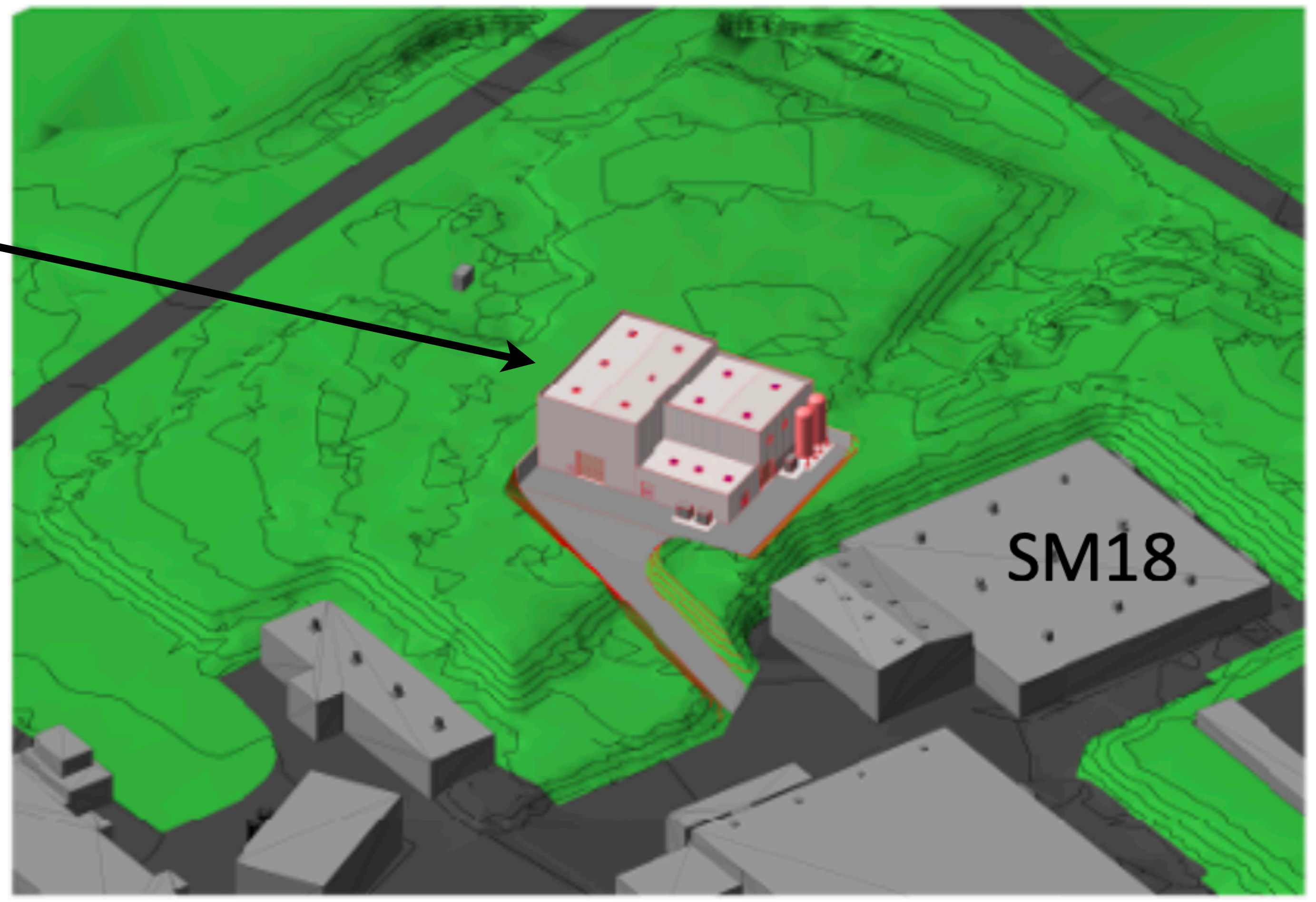


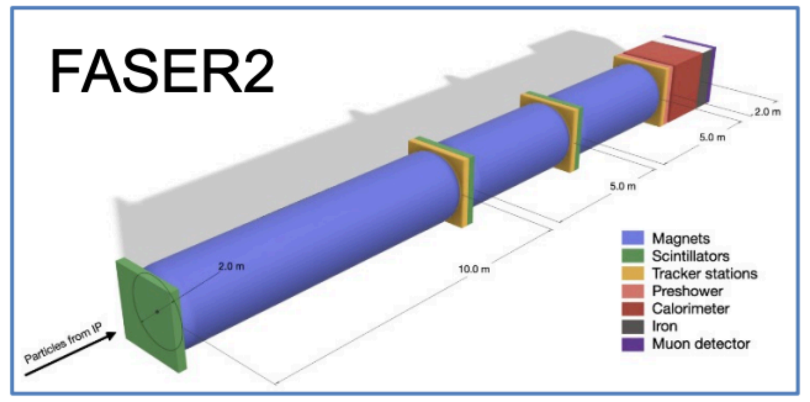
FPF Timeline

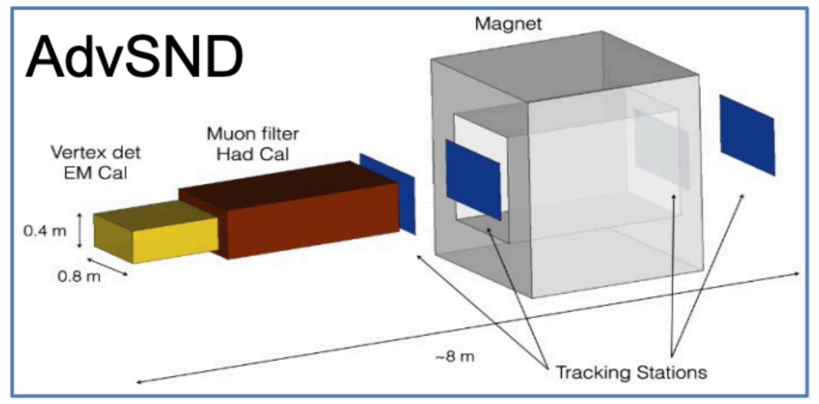


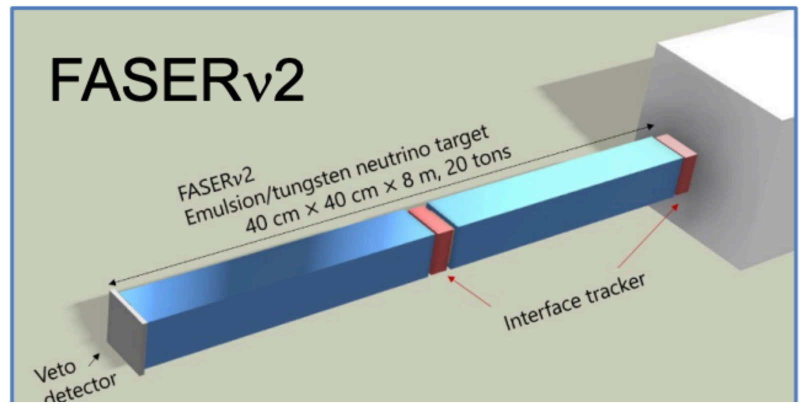


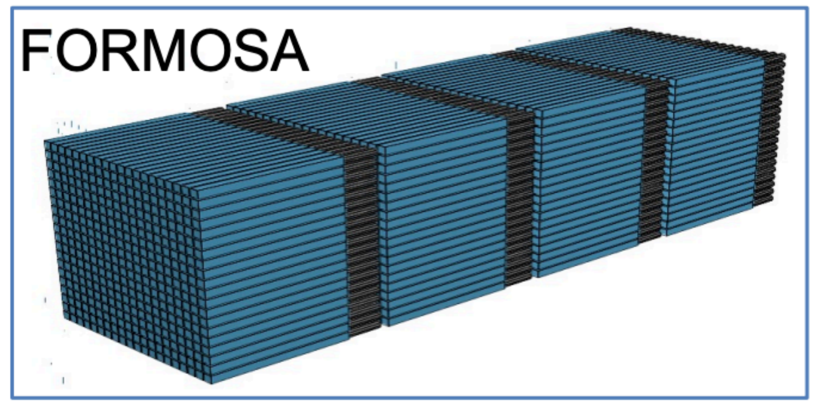


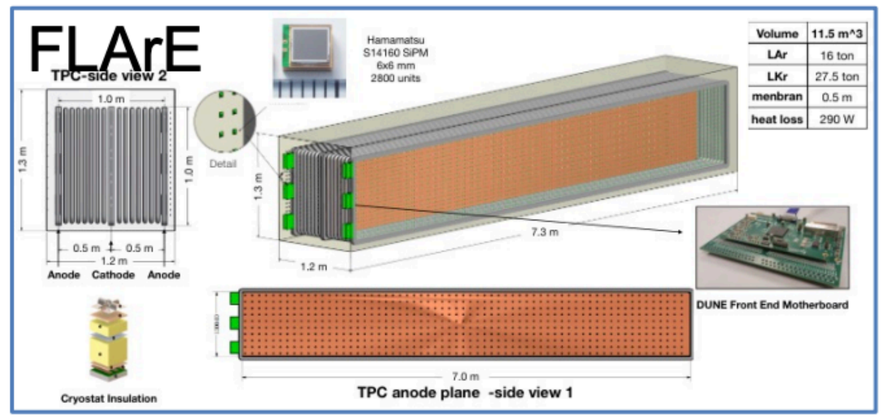












Proposed Experiments

FPF Physics Potential

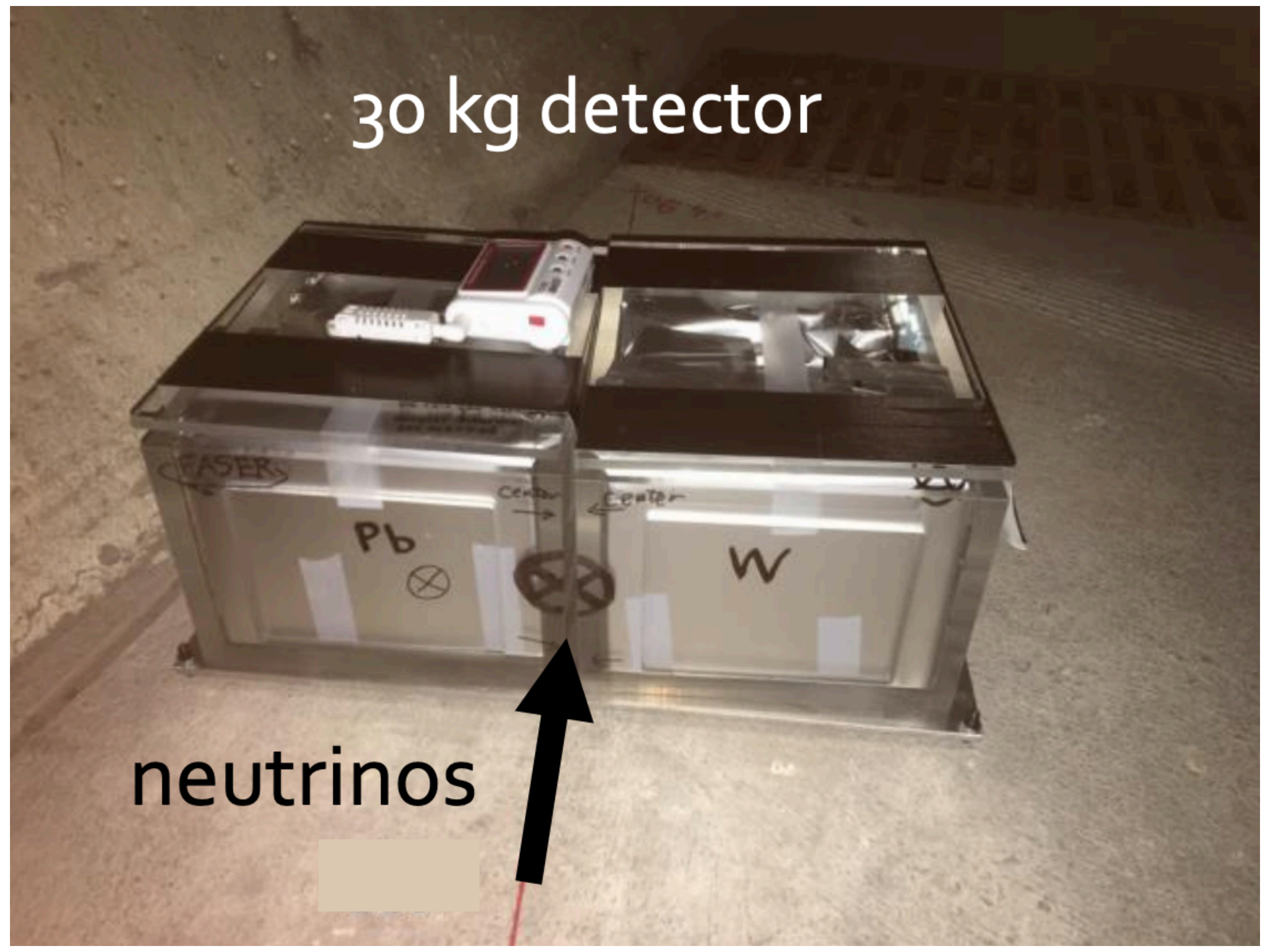
- Example:

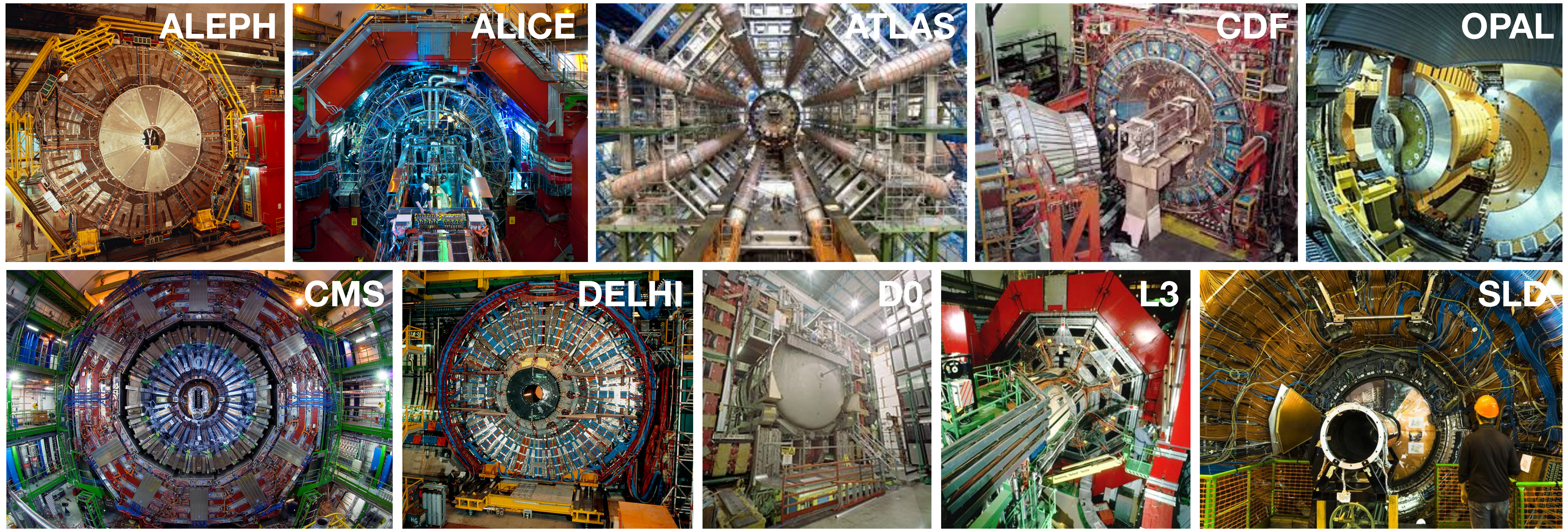
FASERν pilot detector vs. All previous collider experiments

FASERν pilot detector:
- Suitcase size, 4 weeks of data
- Costs: $0 (recycled parts)
- 6 TeV neutrino candidates

[FASER Collaboration, Phys. Rev. D 104 (2021)]

All previous collider experiments:
- Building size, decades of data
- Costs: ~ $$10^9$
- 0 TeV neutrino candidates





FPF Physics Potential

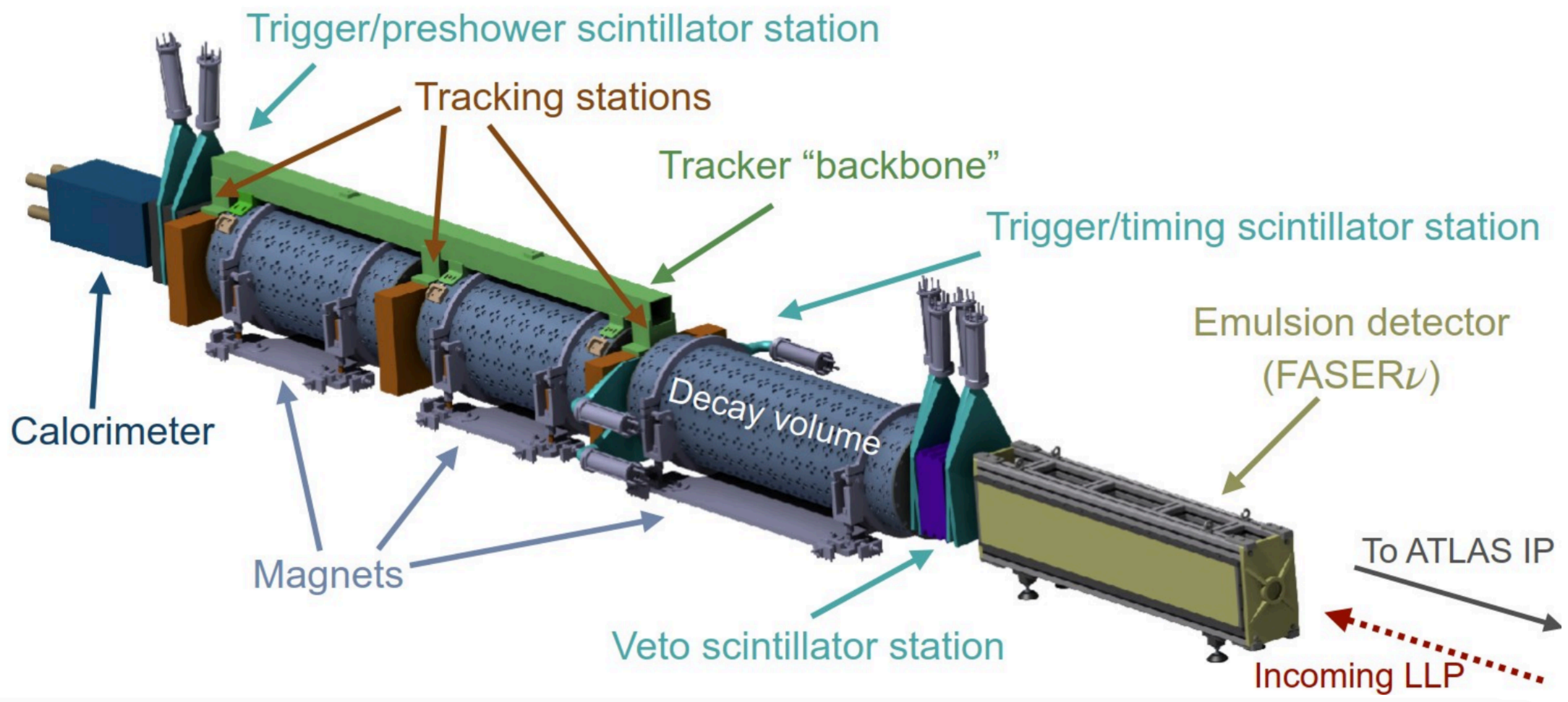
- Example:

FASERν pilot detector vs. All previous collider experiments

FASERν pilot detector	All previous collider experiments
Suitcase size, 4 weeks of data	Building size, decades of data
Costs: \$0 (recycled parts)	Costs: ~ $\$10^9$
6 TeV neutrino candidates	0 TeV neutrino candidates

[FASER Collaboration, Phys. Rev. D 104 (2021)]

- FASERν years 2022-2024:
  - ~ 10000 ν candidates expected (~ 10^9 muons*)
- Forward Physics Facility, FASERν2:
  - ~ 10^6 ν candidates expected! (~ 10^{12} muons*)



*origin not well understood, further studies needed

FPF Physics Potential

- Example:

FASERν pilot detector — vs. — All previous collider experiments

FASERν pilot detector	All previous collider experiments
Suitcase size, 4 weeks of data	Building size, decades of data
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[FASER Collaboration, Phys. Rev. D 104 (2021)]

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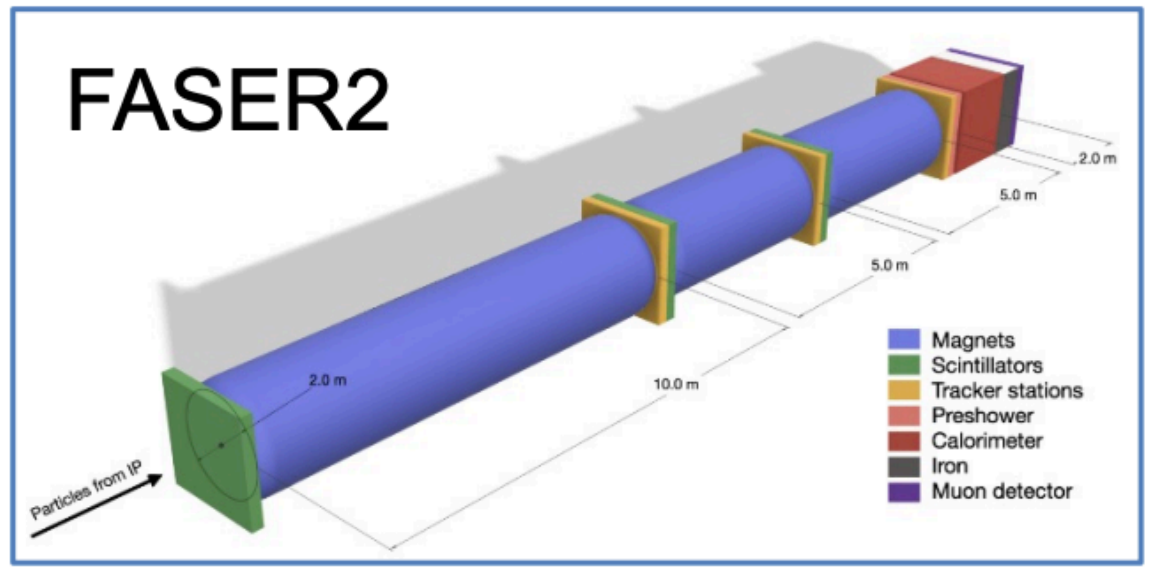
  - ~ 10^6 ν candidates expected! (~ 10^{12} muons*)

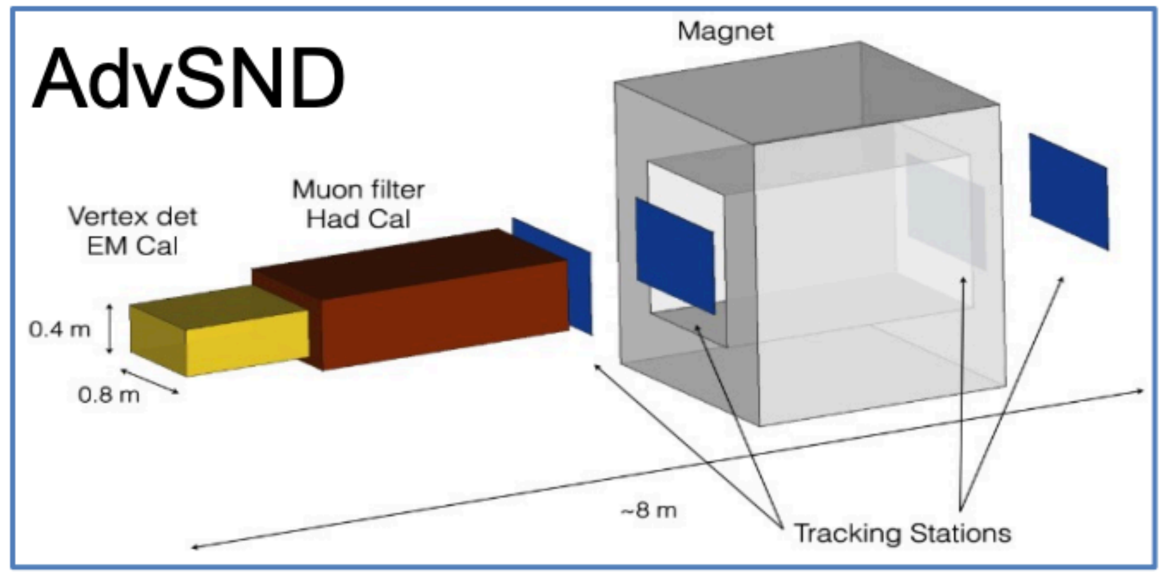
See Felix Kling's talk next week!

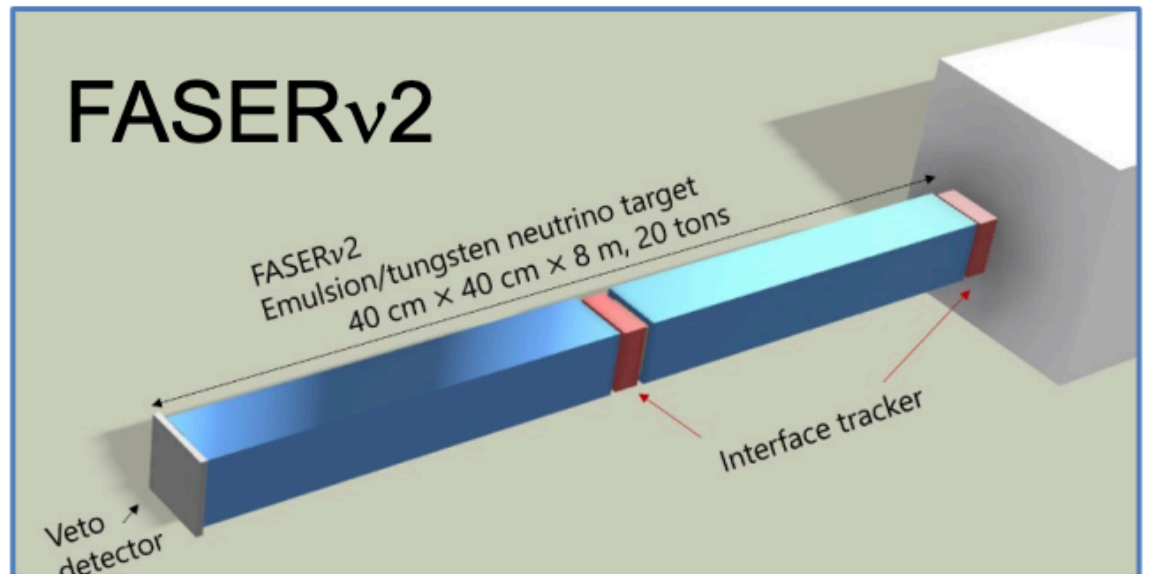
*origin not well understood, further studies needed

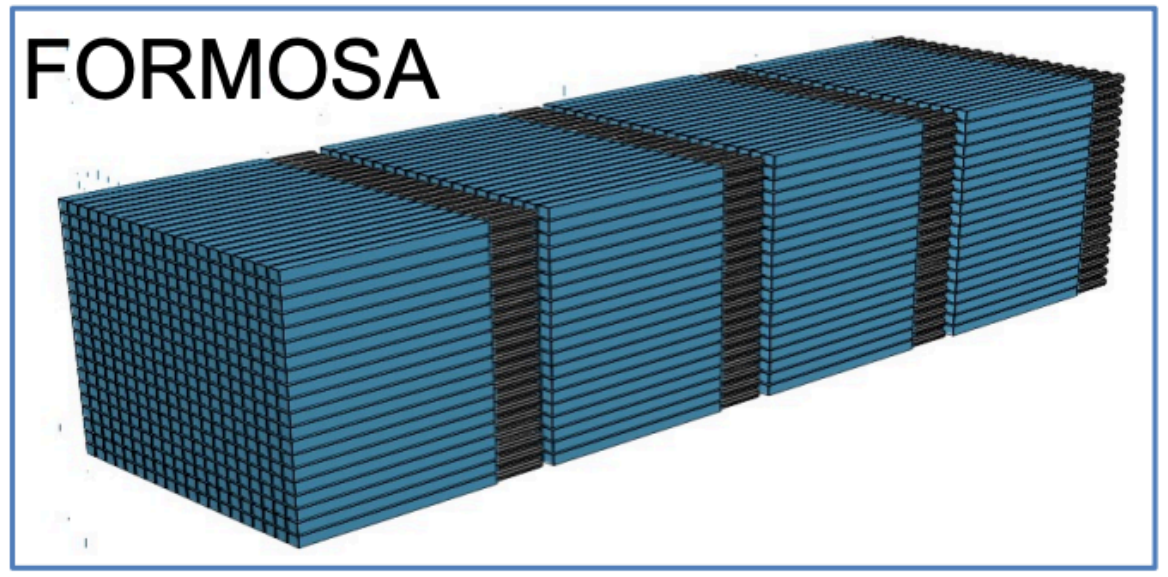
Proposed FPF Experiments

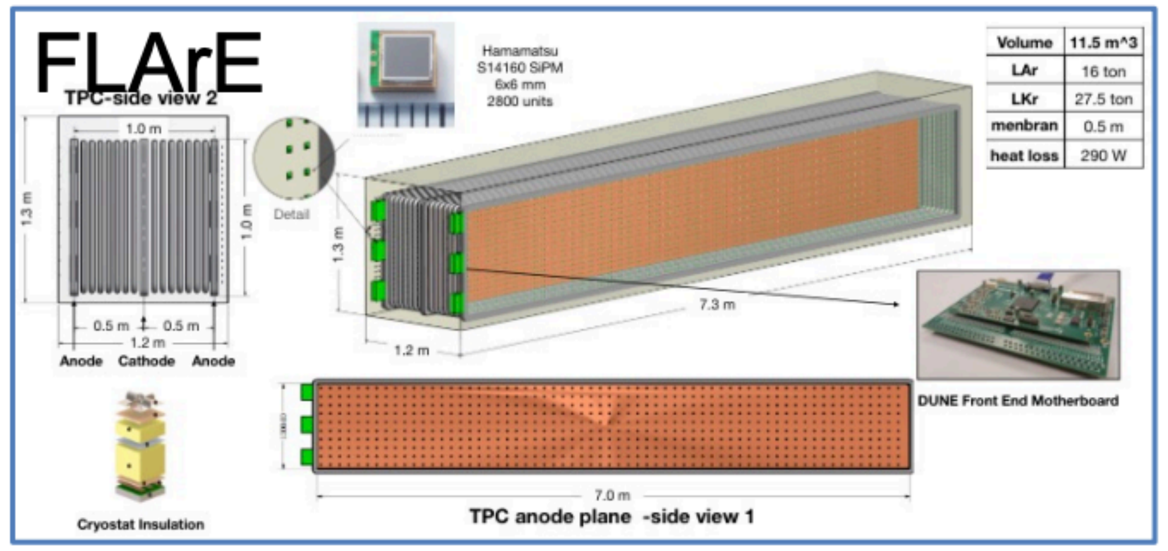
- Five proposed experiments* with different (main) physics goals:
  - FASER2
    - Long-lived particles
  - FASERν2
    - TeV neutrinos
  - AdvSND
    - TeV neutrinos
  - FORMOSA
    - BSM physics: millicharged particles
  - FLArE
    - TeV neutrinos & light dark matter
- Details of detector designs under investigation…







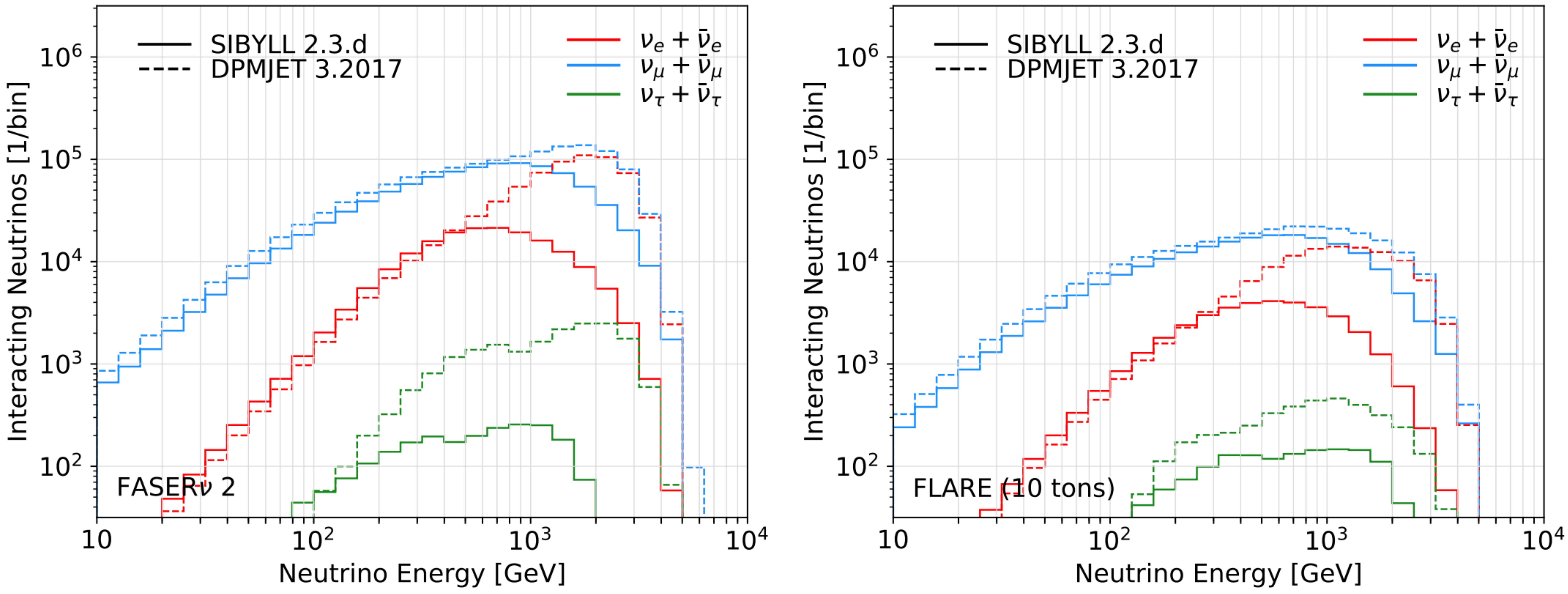




* for a complete description of the experiments, please see the FPF white paper

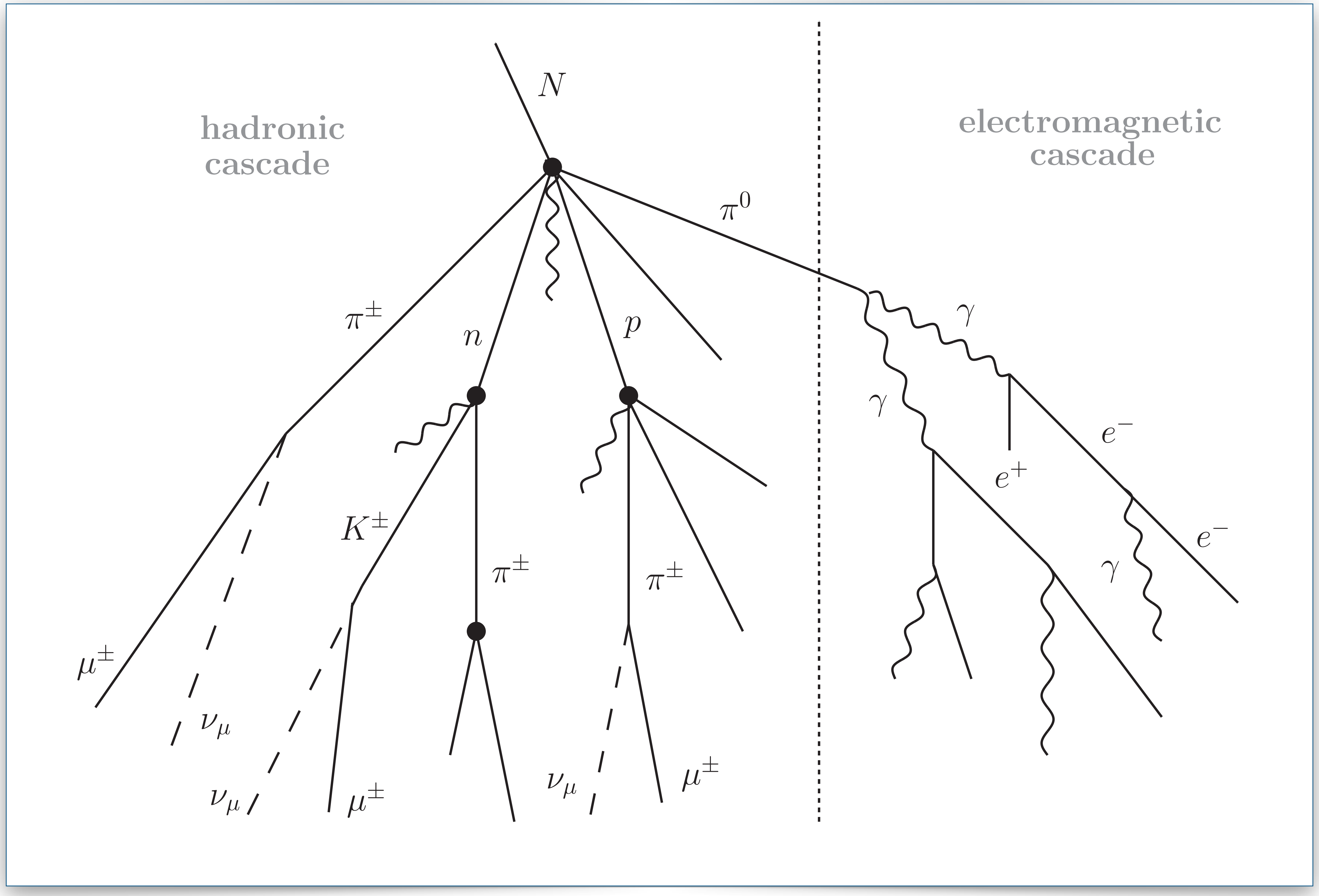
Expected Neutrino Interactions

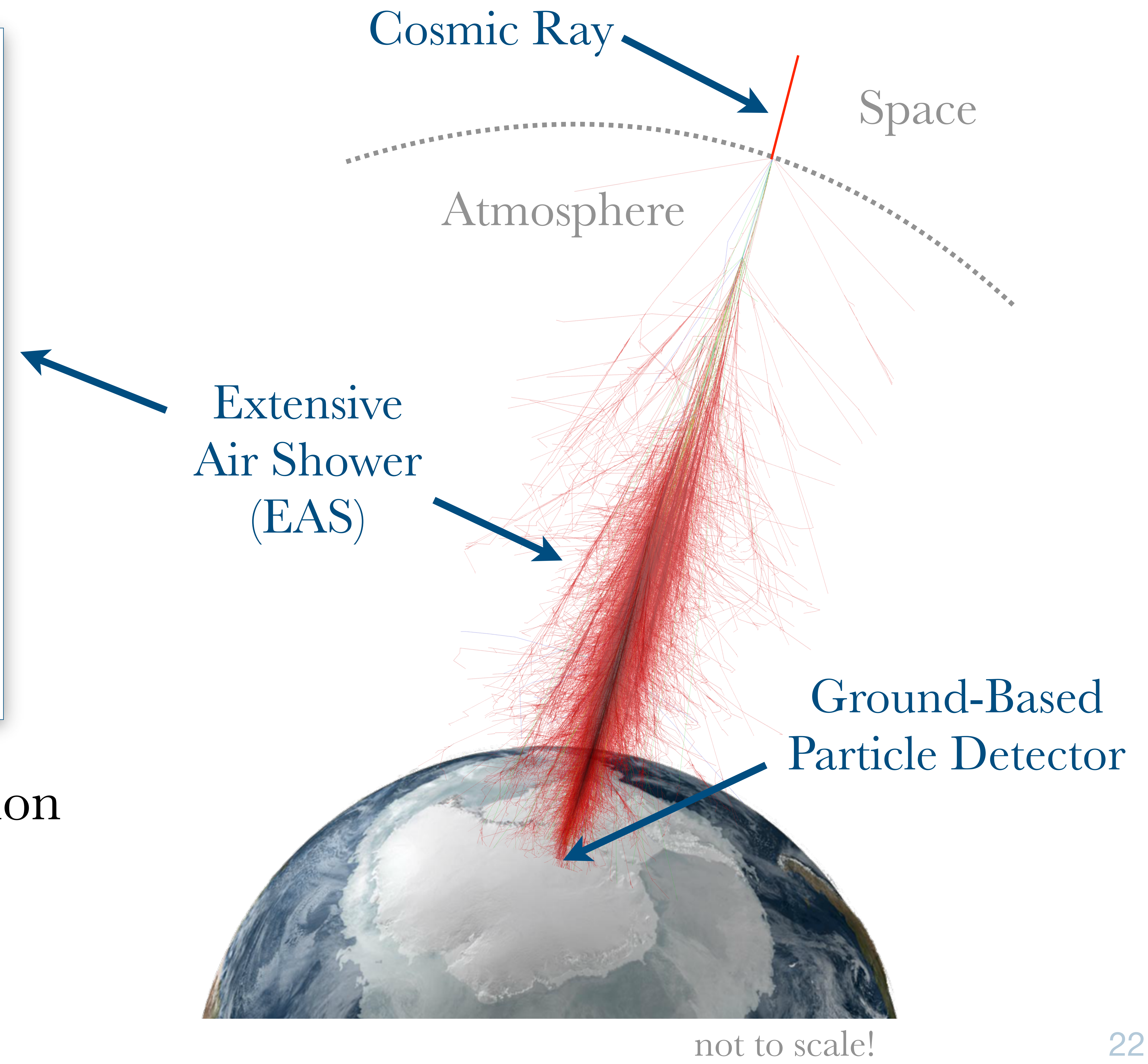
- FASERν2 (20 ton) and FLArE (10 ton) during HL-LHC era (3000 fb^{-1} integrated luminosity)



Astroparticle Physics and Light Hadron Production at the FPF

Extensive Air Showers

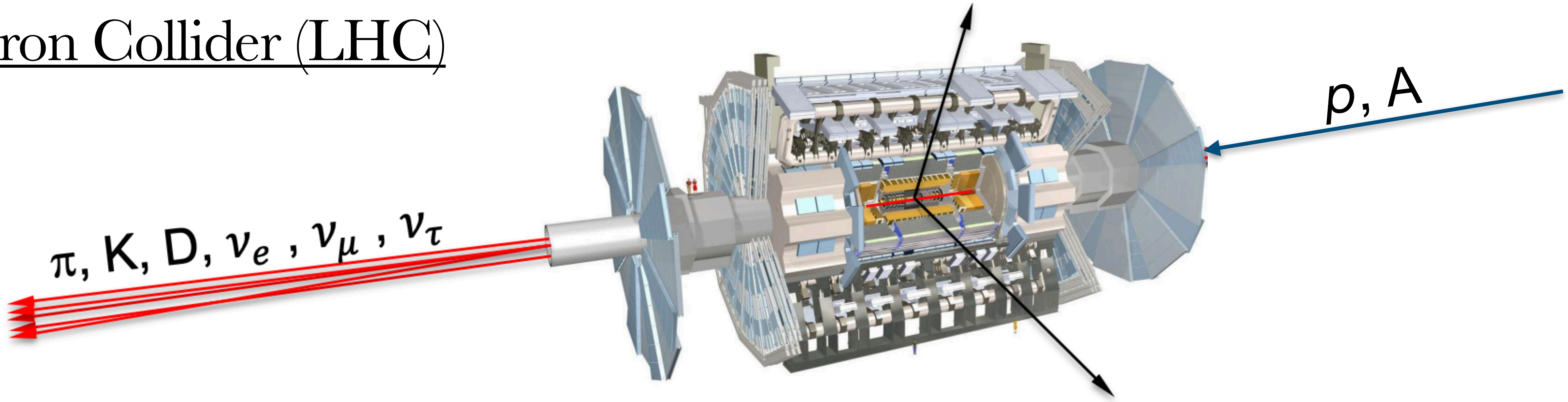




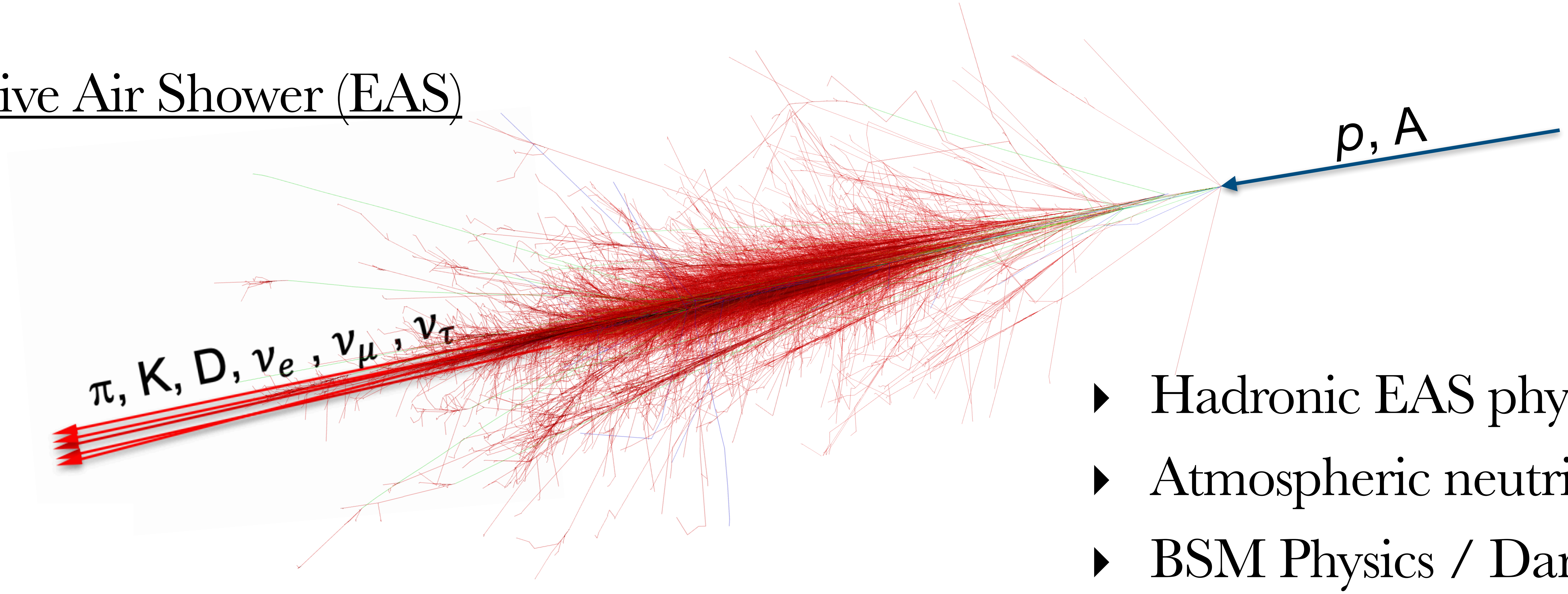
- EAS are driven by (light) hadron production
- EAS are the connection between cosmic ray and particle physics!

EAS vs. Collider

- Large Hadron Collider (LHC)



- Extensive Air Shower (EAS)

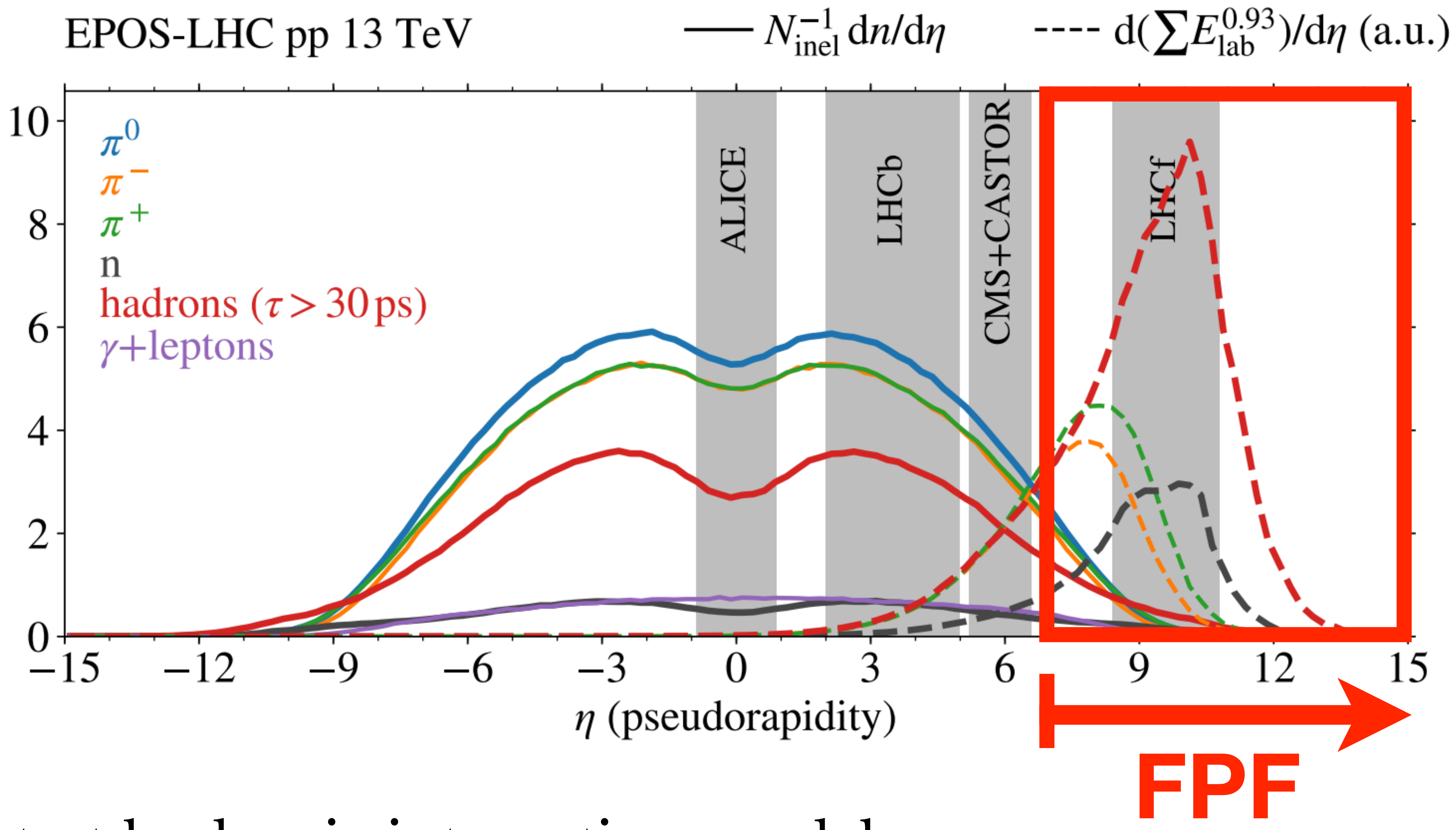


- Hadronic EAS physics
- Atmospheric neutrino production
- BSM Physics / Dark Matter

Motivation I

- Extensive air showers:
  - Particle production in the far-forward region
  - Low momentum transfer
  - Non-perturbative regime
  - Complex particle composition
  - Energies range over many orders of magnitude
- Modeling of particle interactions based on phenomenological models developed for EAS simulations

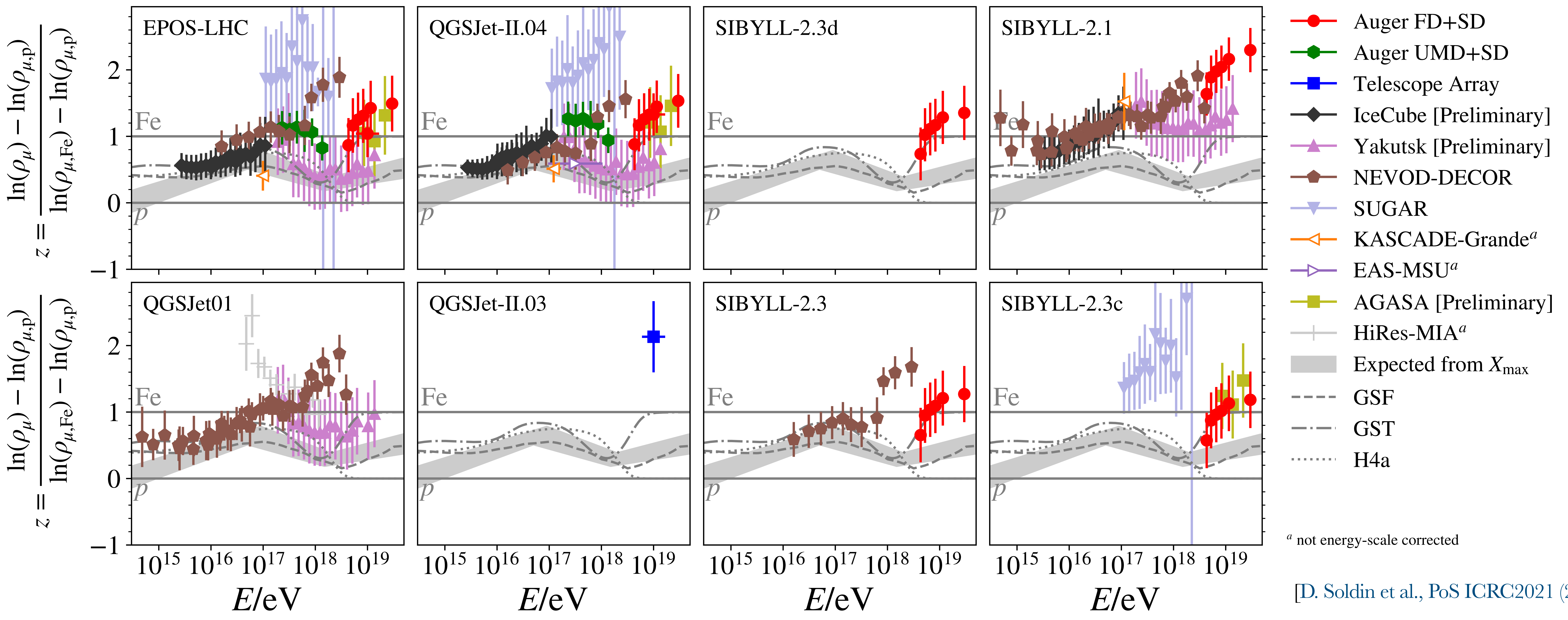
[J. Albrecht, D. Soldin, et al., Astrophys. Space Sci. 367 (2022)]



- FPF will provide unique opportunities to test hadronic interaction models

Motivation I

- Large discrepancies between data and MC observed in EAS

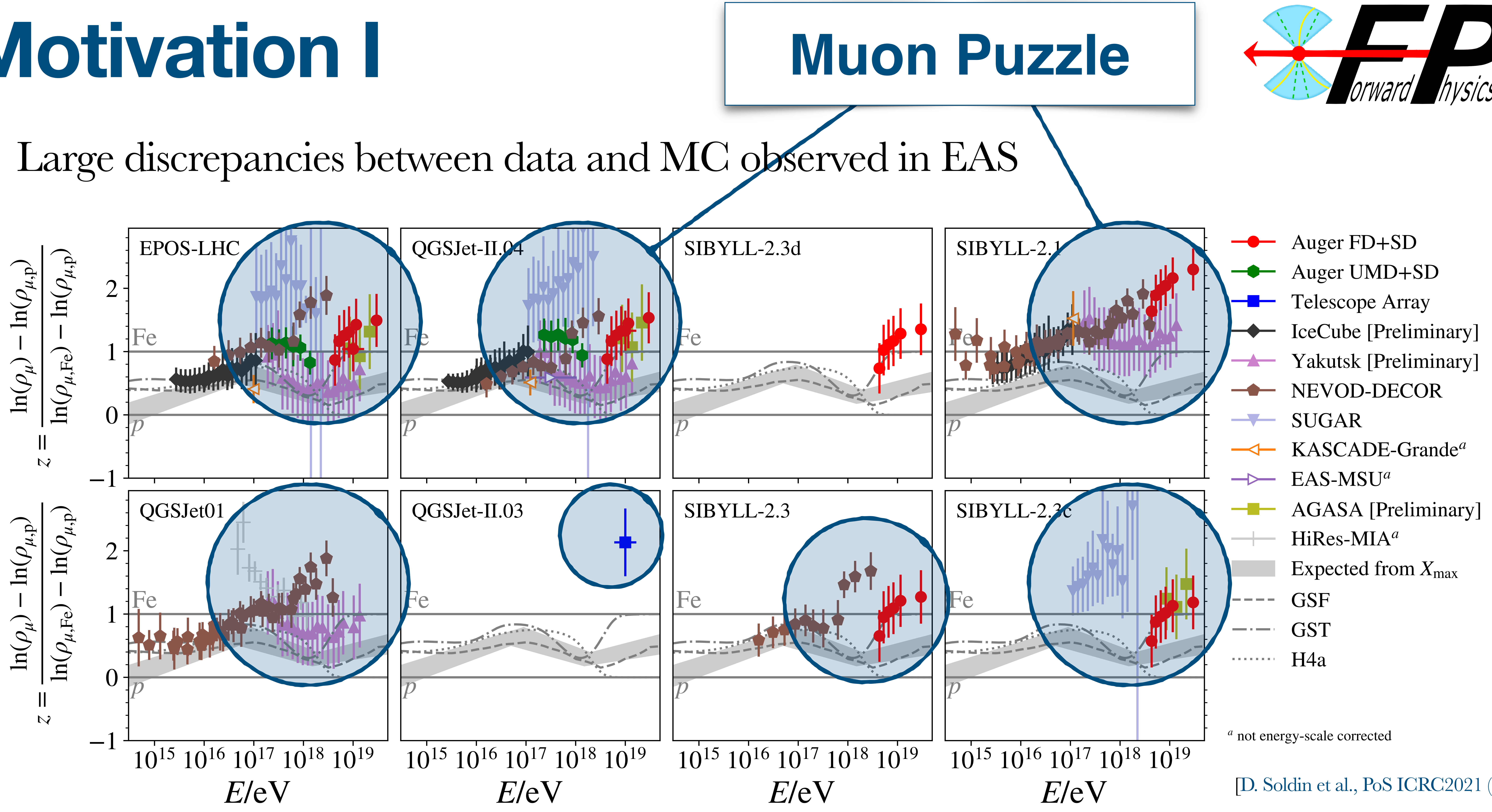


[D. Soldin et al., PoS ICRC2021 (2021) 349]

- Muon measurements and models indicate composition heavier than iron at high energies!

Motivation I

- Large discrepancies between data and MC observed in EAS



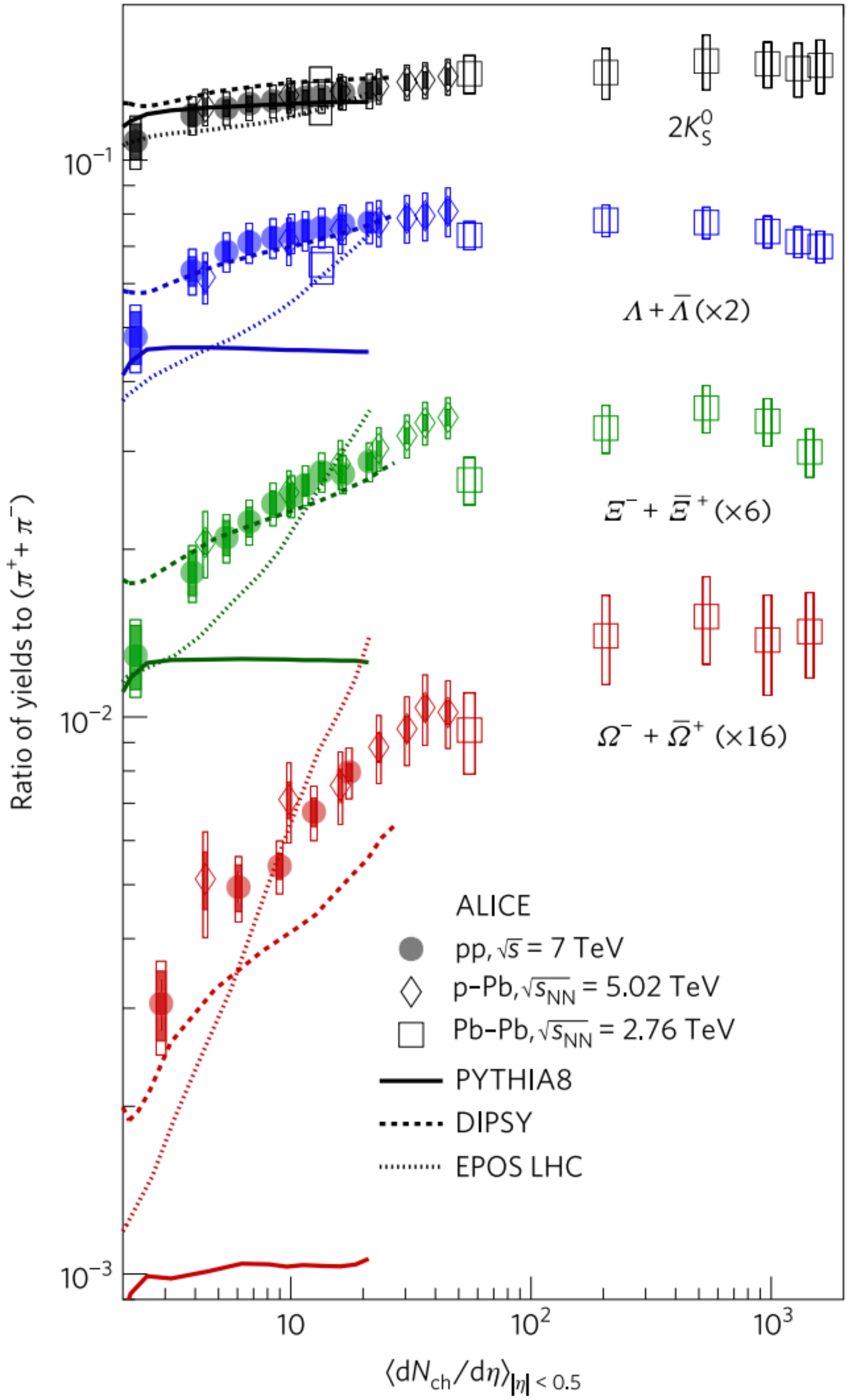
[D. Soldin et al., PoS ICRC2021 (2021) 349]

- Muon measurements and models indicate composition heavier than iron at high energies!

Motivation II

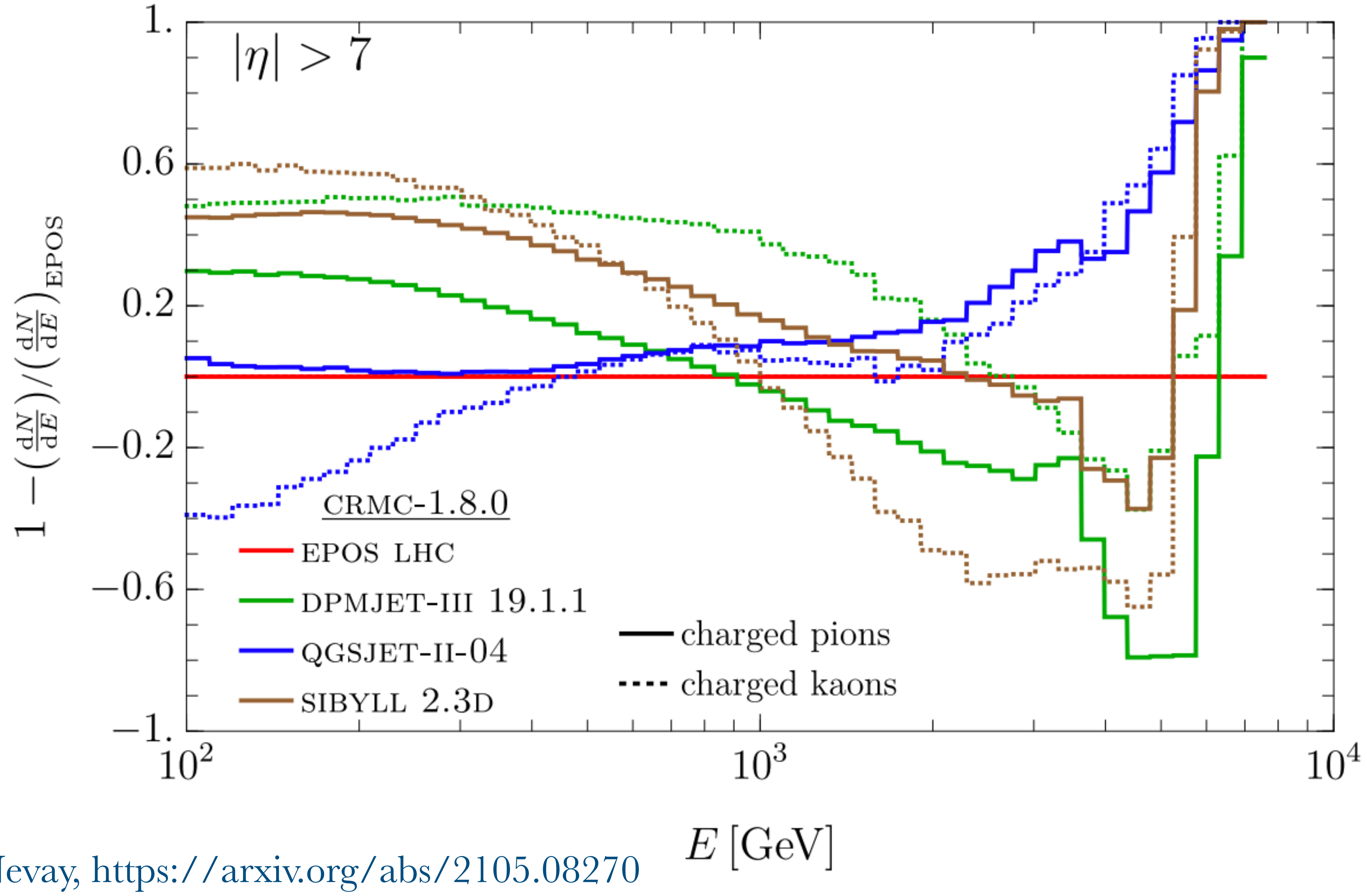
- Evidence for strangeness enhancement reported by ALICE
- Universal enhancement of strangeness production in high-multiplicity events at mid-rapidity ($|y| < 2$)
- Depends on the multiplicity of the event at mid-rapidity, not on the details of the collision system!
- Can this effect also be seen in hadrons produced at forward rapidities?
- Possible explanation for the Muon Puzzle in EAS…?
- <u>FPF provides unique opportunities for testing the forward rapidity region!</u>

[ALICE Collaboration, Nature Phys. 13, 535 (2017)]



Light Hadron Production

- Neutrino fluxes at the FPF:
  - Ratio of electron and muon neutrinos is a proxy for the ratio of charged pions and kaons
  - Electron and muon neutrino fluxes populate different energy regions which will help to disentangle them
  - Neutrinos from pion and kaon decays have different rapidity distributions which will help to disentangle them
  - Fast simulation package* available! (F. Kling)
  - Further studies needed:
    - MC based on different generators
    - Neutrino fluxes in different detectors
    - Tests of dedicated strangeness (muon) enhancement models, sensitivities

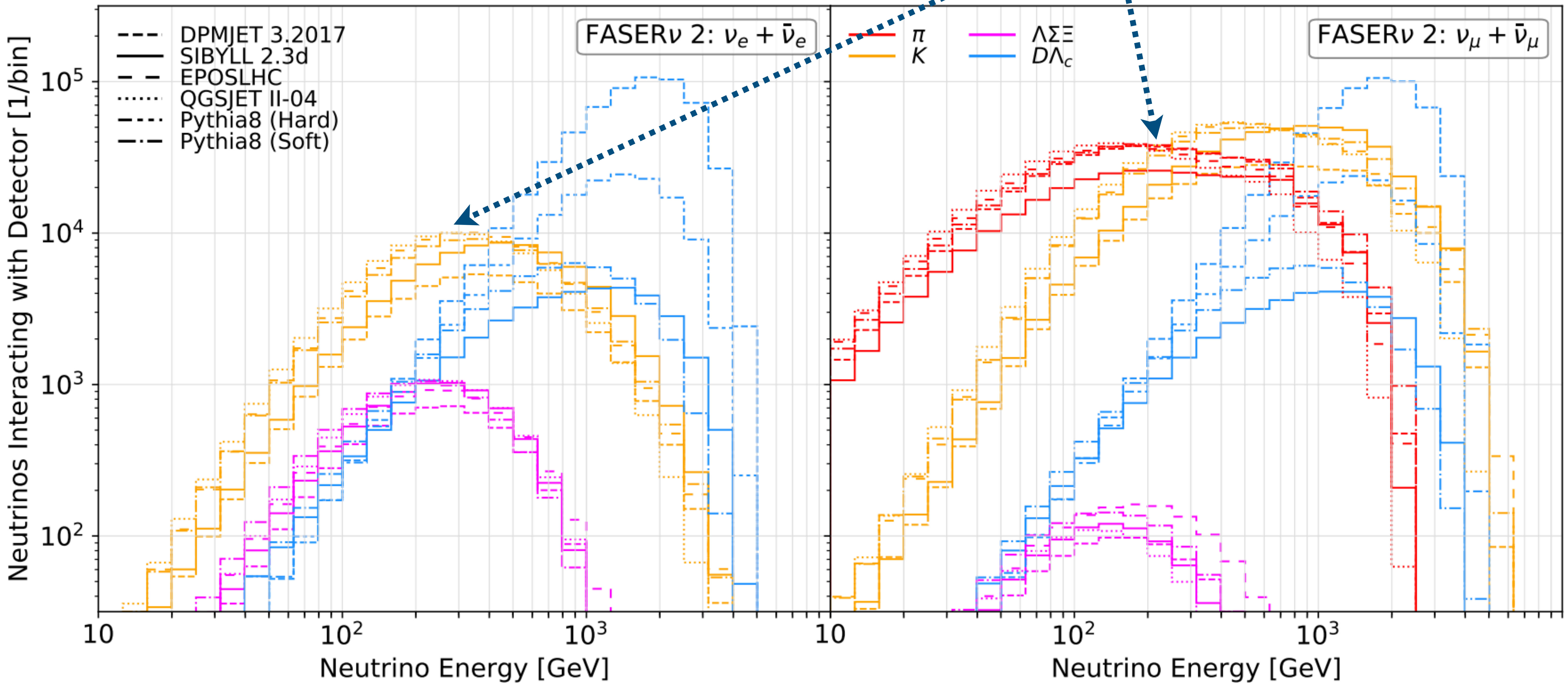


* Simulation code available at: https://github.com/KlingFelix/FastNeutrinoFluxSimulation, see also F. Kling, L. Nevay, https://arxiv.org/abs/2105.08270

Light Hadron Production

- Example: Neutrino fluxes at FASERν2

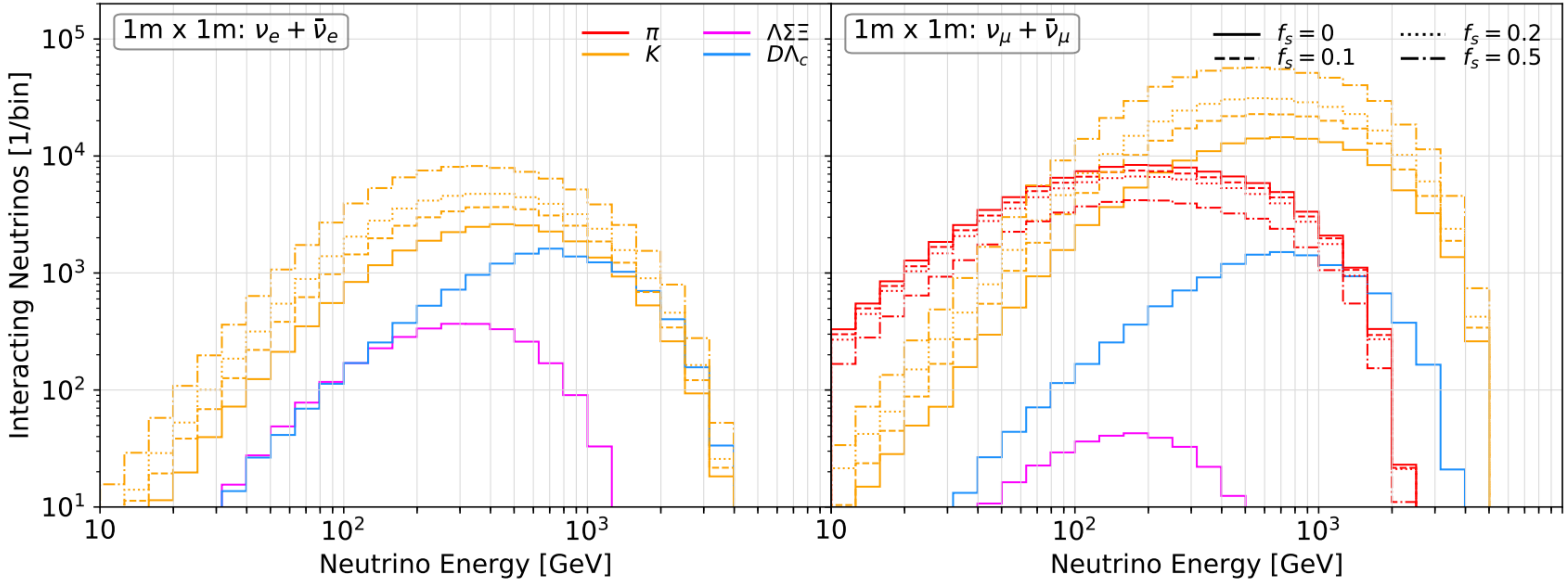
low-energy region relevant!



- Predictions differ by a factor of up to 2, much bigger than the anticipated FPF uncertainties!

Light Hadron Production

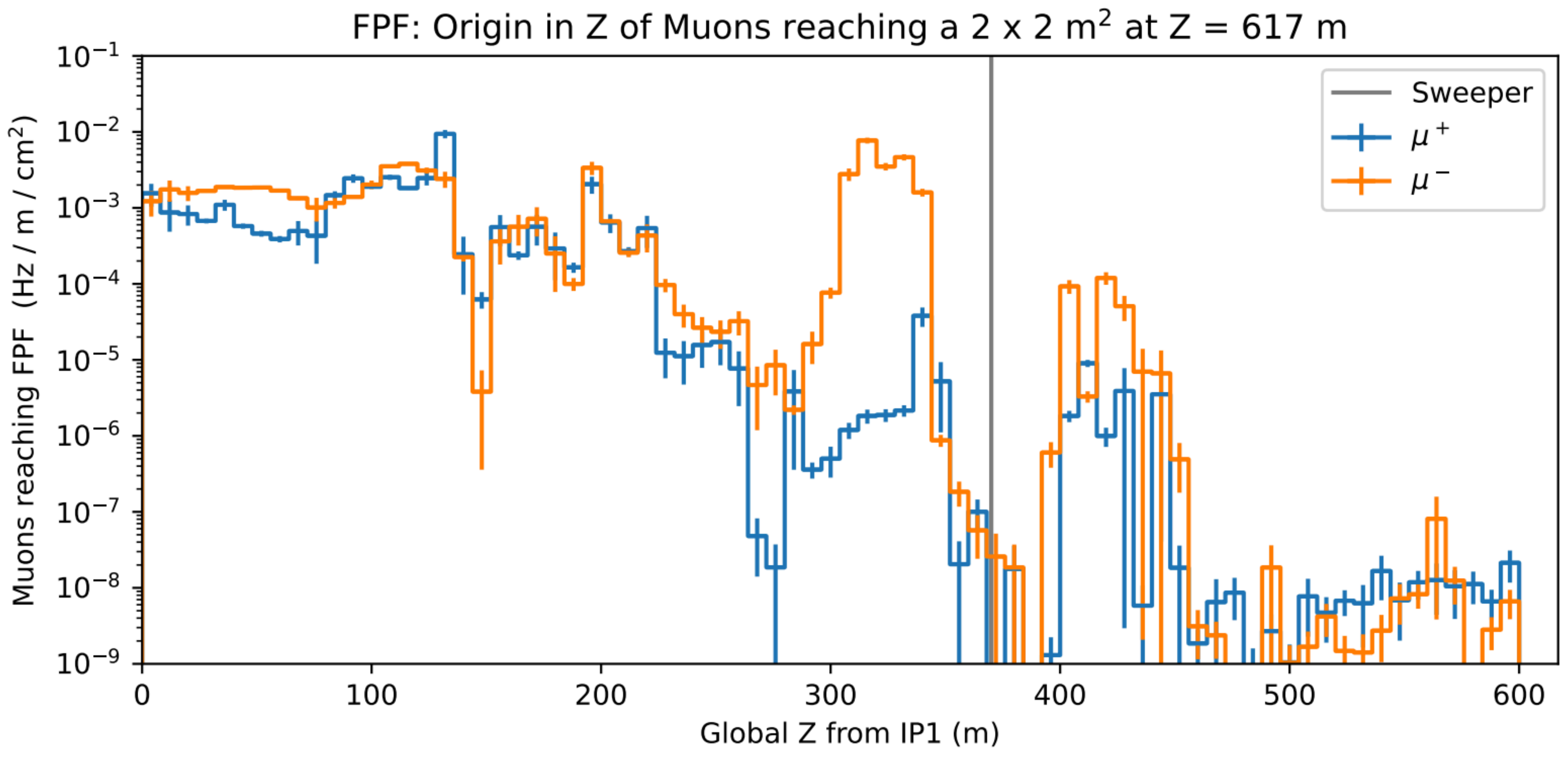
- Example: Neutrino fluxes at FLArE



- Model comparison: strangeness enhancement toy model [L. Anchordoqui et al., JHEAp 34 (2022)]

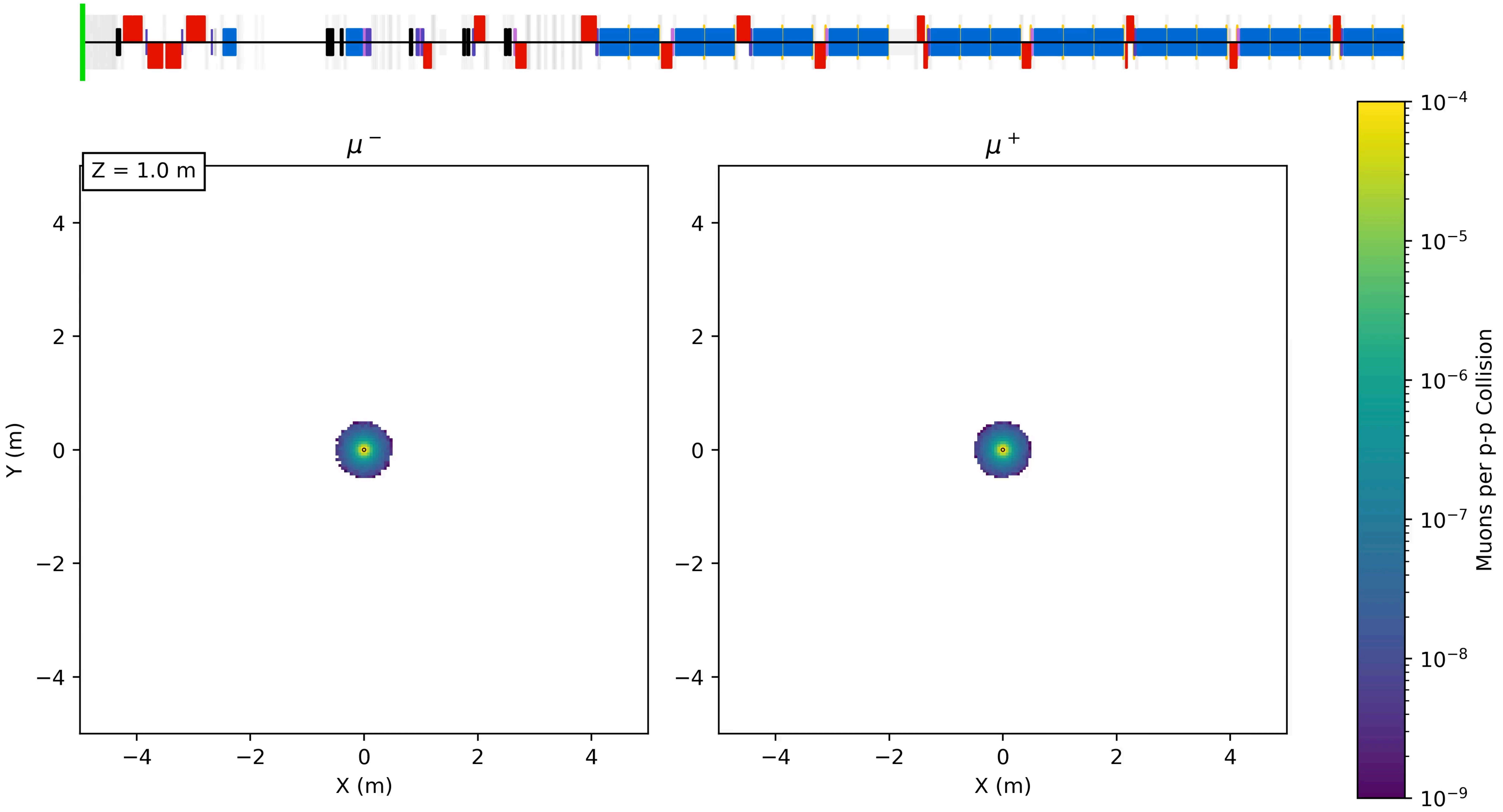
Light Hadron Production

- Muon fluxes at the FPF:
  - Large muon flux at the FPF, e.g. ~1 Hz per cm² in FASER2
  - Challenging to study as the origin of production is uncertain…
  - BDSIM/Geant4 simulations available, including full muon history (L. Nevay)
  - Open questions:
    - Can we use muons to study light hadron production?
    - Can we measure the muon charge ratio?
    - Do sweeper magnets help our physics case?
    - What can we learn from muon fluxes measured at FASER and SND@LHC?
- Dedicated studies of the muon yield at the FPF (incl. full muon history) needed!



Light Hadron Production

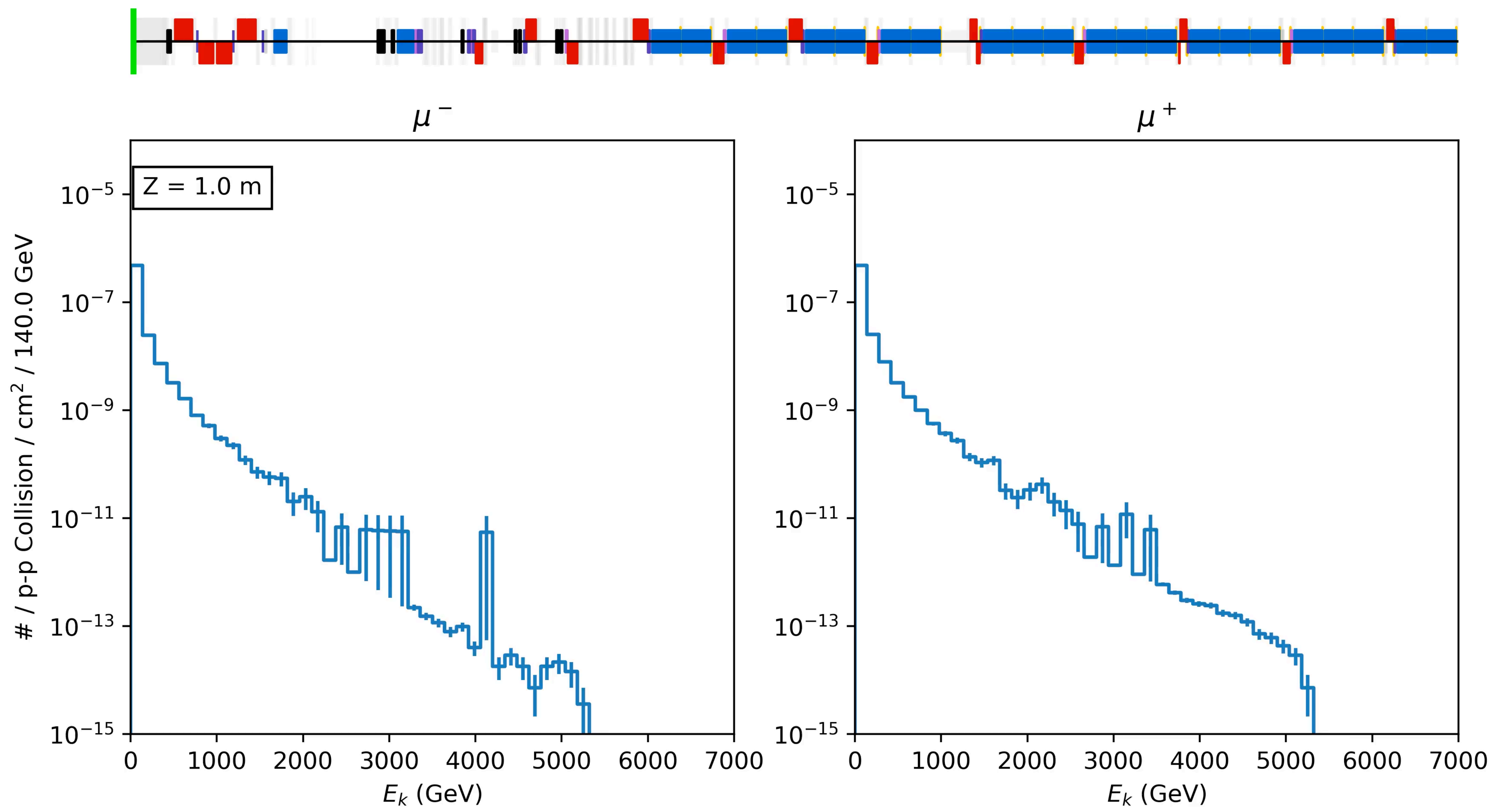
- Simulated muon fluxes at the FPF:



by L. Nevay

Light Hadron Production

- Simulated muon spectra at the FPF:



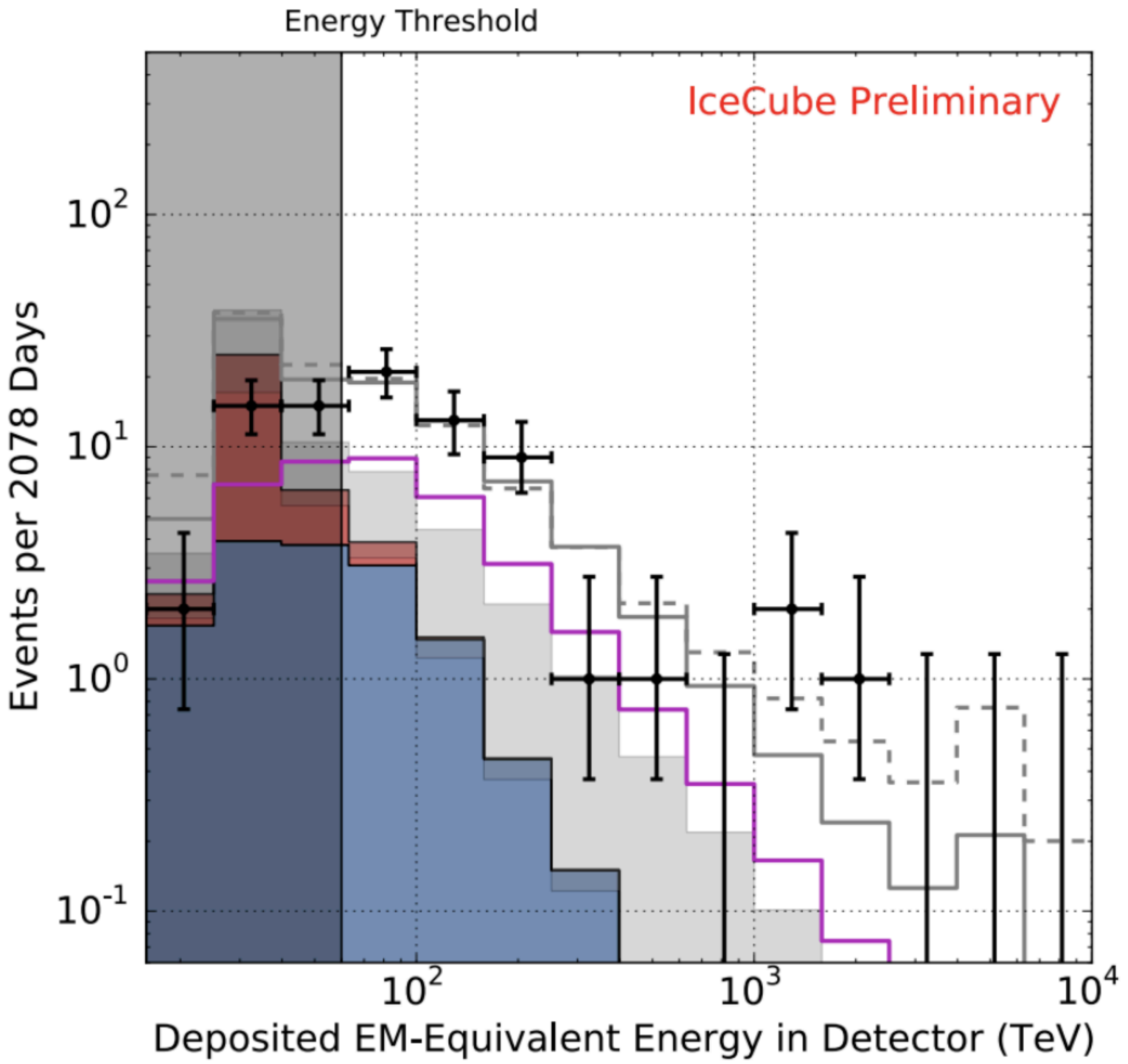
by L. Nevay

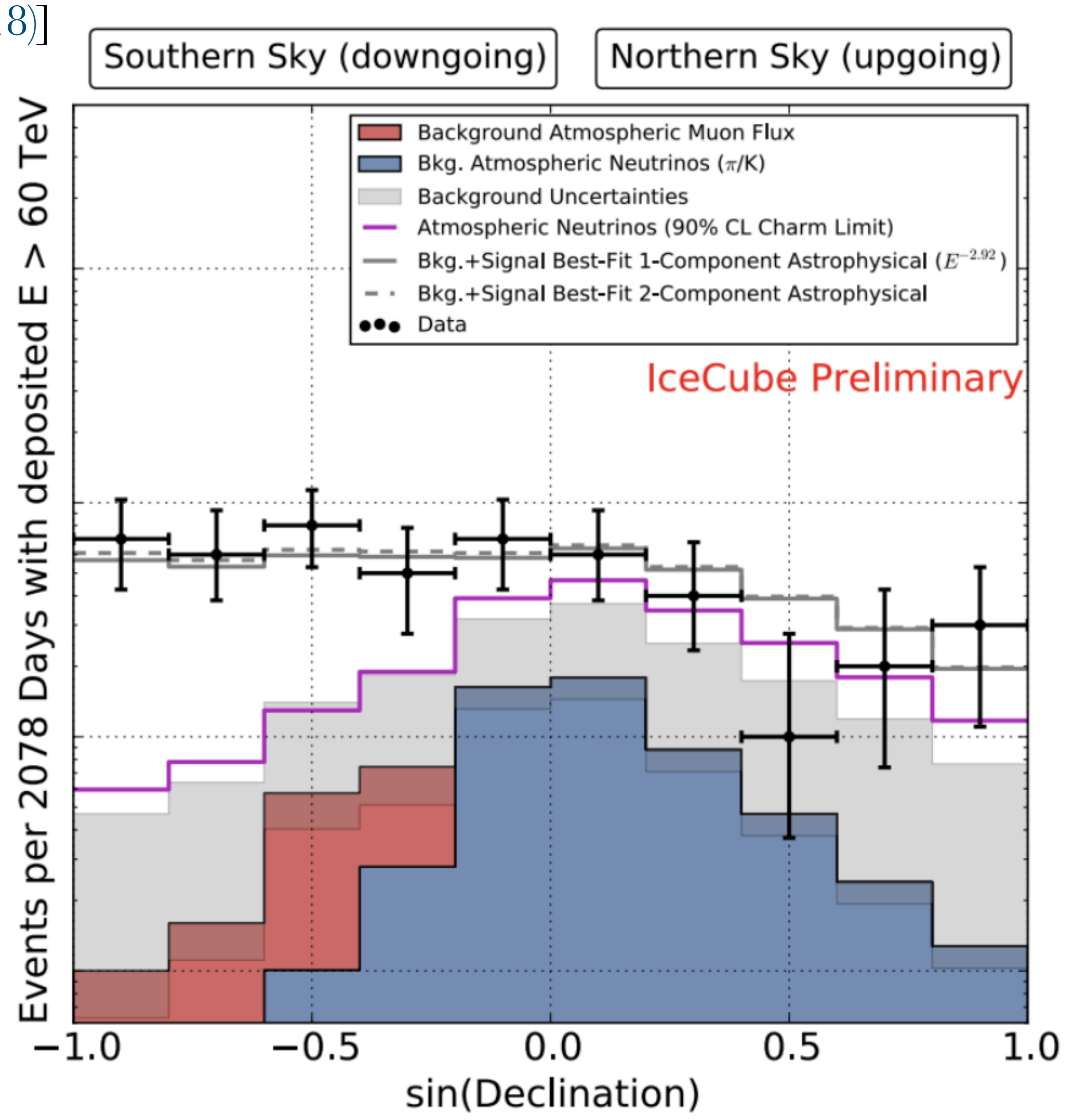
Astroparticle Physics and Neutrino Production at the FPF

Motivation III

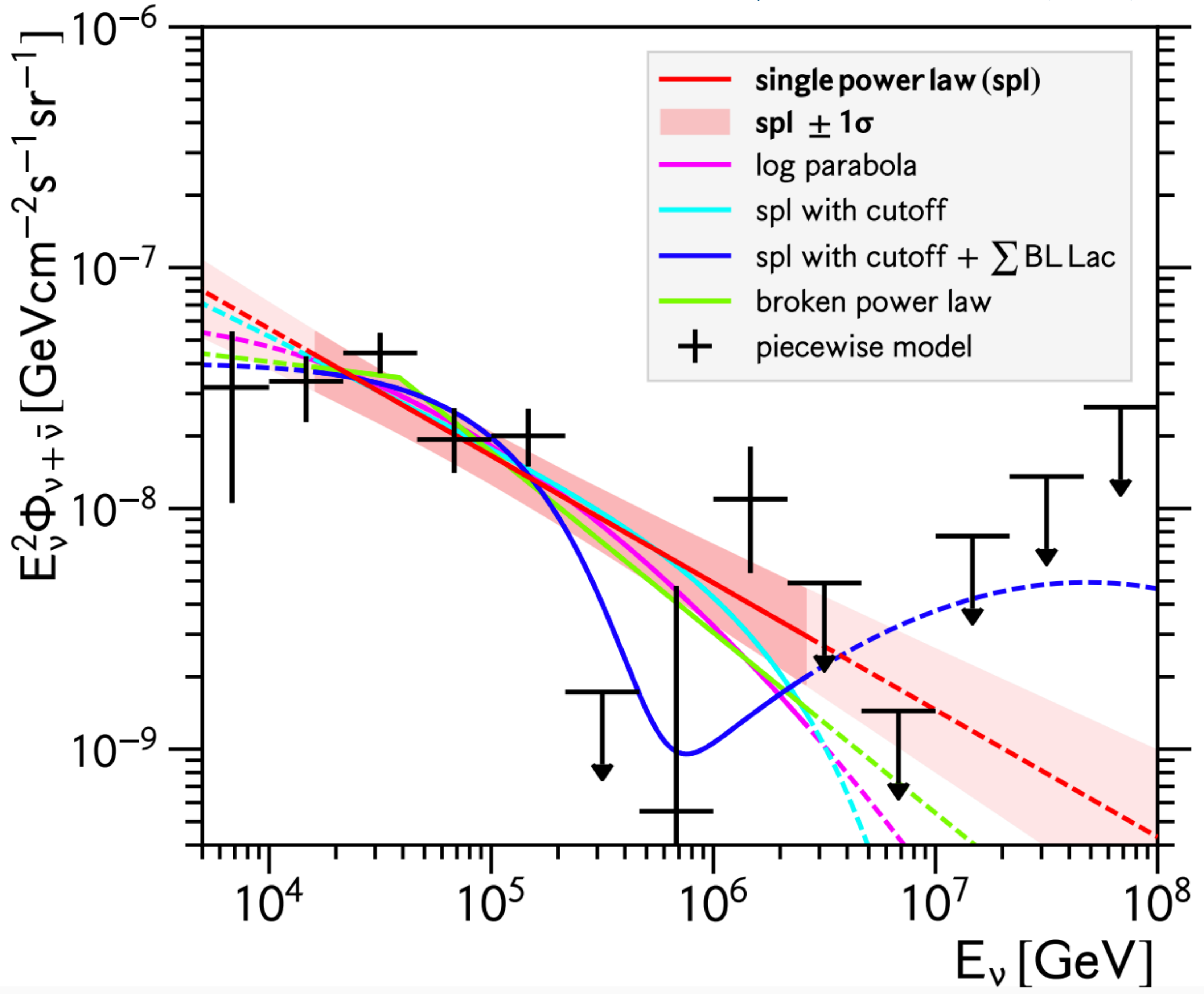
- Atmospheric muons (in particular prompt) are dominant background for astrophysical neutrino searches
- Large uncertainties in prompt neutrino flux calculations
- FPF experiments will directly measure TeV neutrino production

[C. Kopper (IceCube Collaboration), PoS(ICRC2017)981 (2018)]



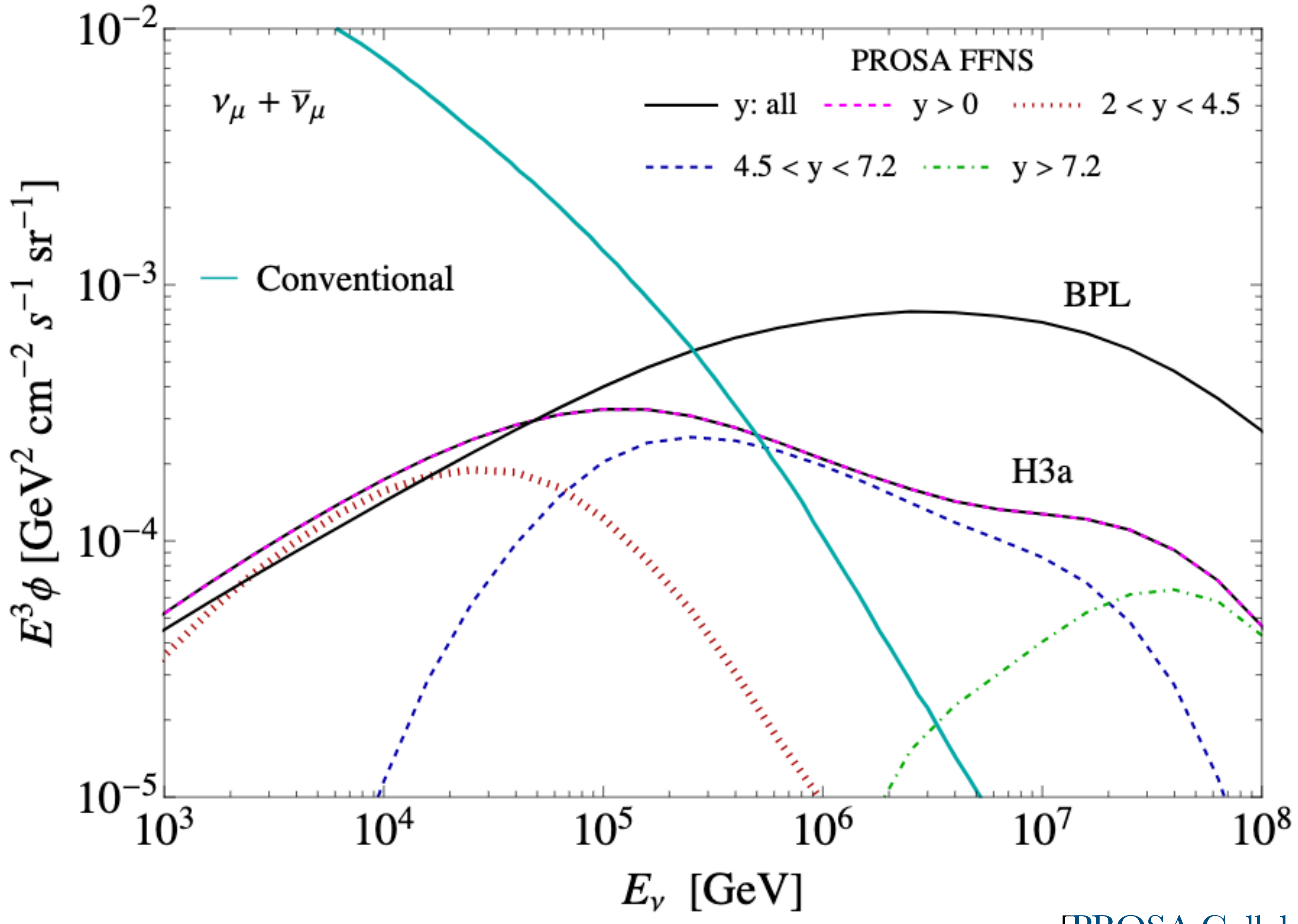


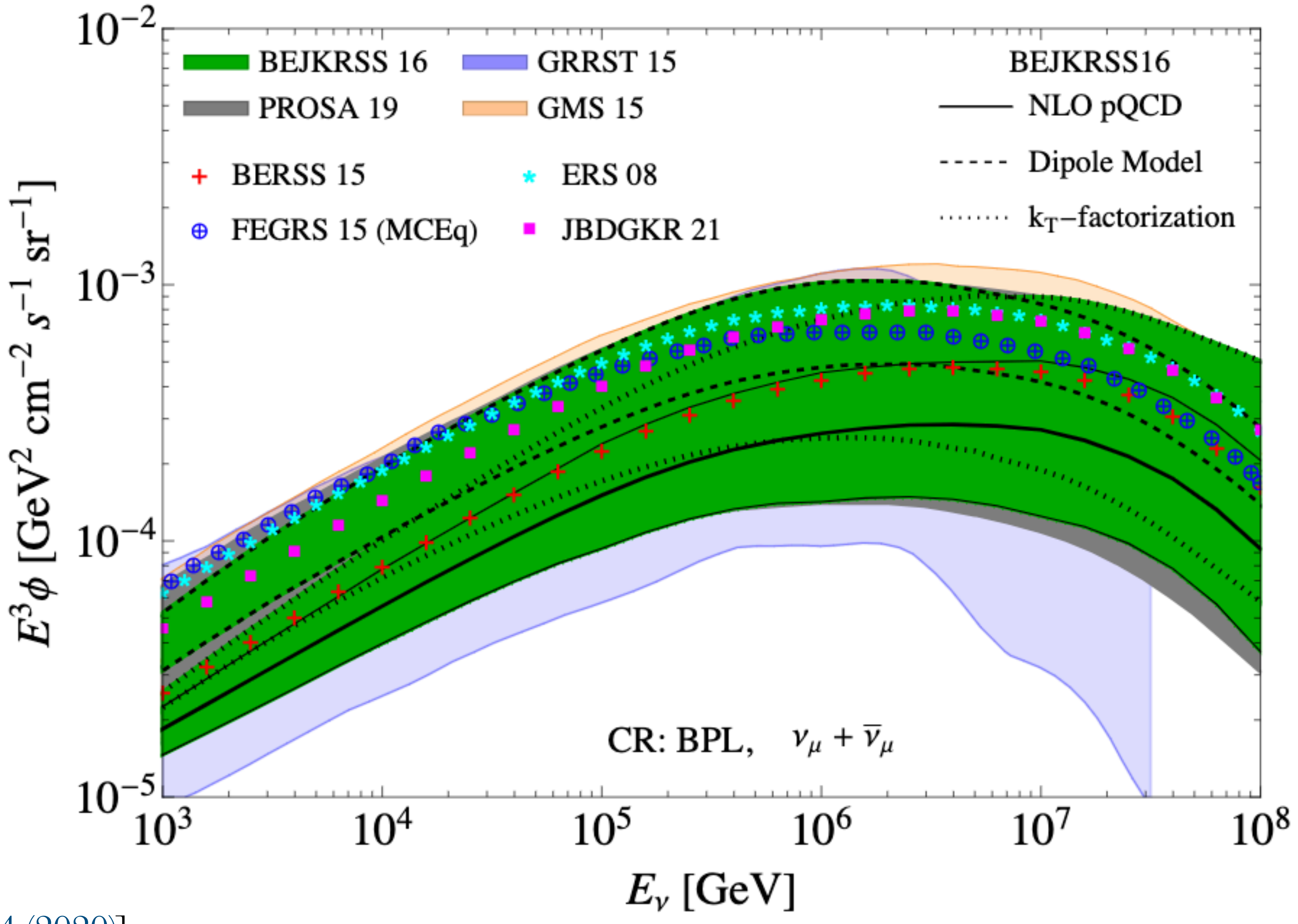
[IceCube Collaboration, Phys. Rev. Lett. 125 (2020)]



Atmospheric Neutrinos

- FPF can provide high-statistics neutrino data over forward rapidity ranges
- Strong constraints on prompt (charmed) neutrino production
- Improvement of prompt atmospheric neutrino models
- Reduced uncertainties of astrophysical neutrino searches (e.g. spectral fits)



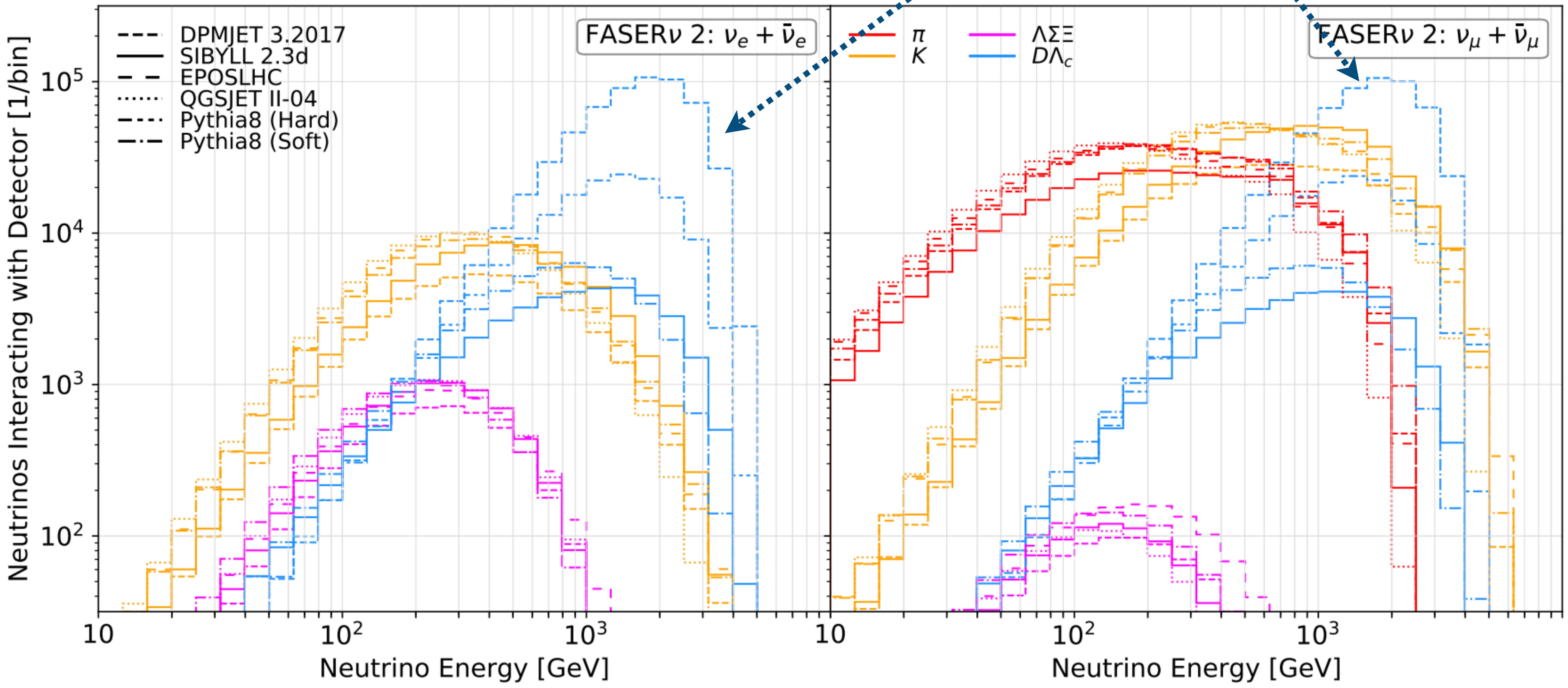


[PROSA Collaboration, JHEP 04 (2020)]

Prompt Neutrino Production

- Example: Neutrino fluxes at FASERν2

high-energy region relevant!

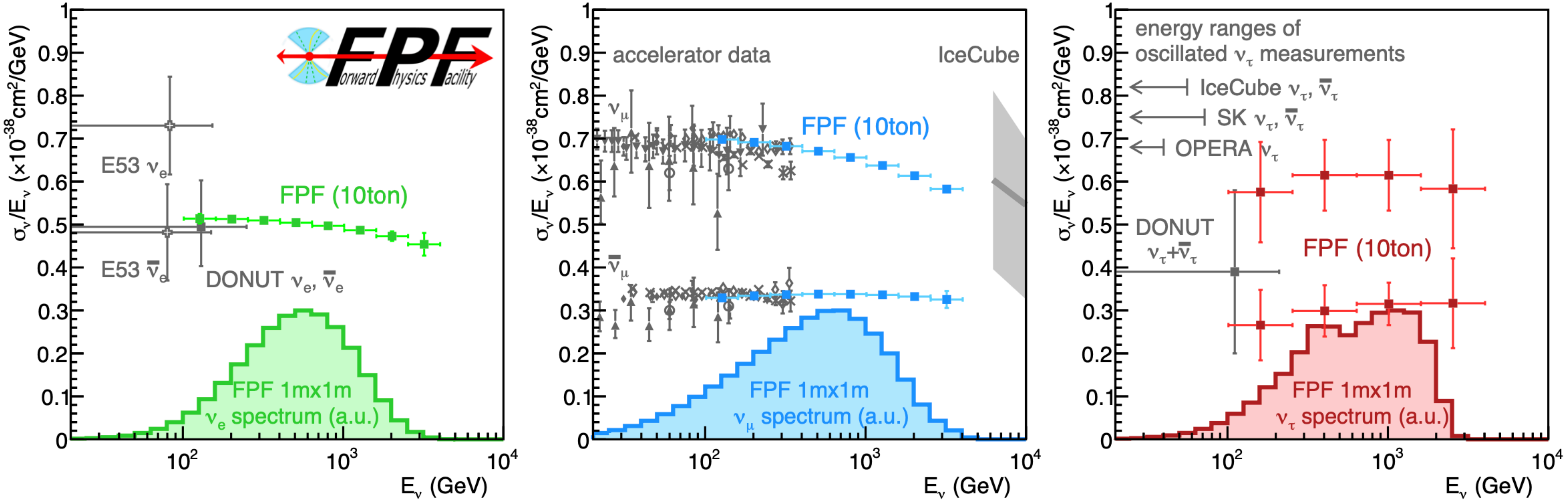


- Prompt neutrino fluxes!

* Simulation code available at: https://github.com/KlingFelix/FastNeutrinoFluxSimulation, see also F. Kling, L. Nevay, https://arxiv.org/abs/2105.08270

Neutrino Interactions

- Example: Neutrino-nucleon cross sections, FLArE (10 ton, 1mx1m)



- Many more precision measurements of neutrino properties, e.g. PDFs, charm, BSM physics
- Will improve modeling of neutrino fluxes in IceCube, Km3NET, etc.

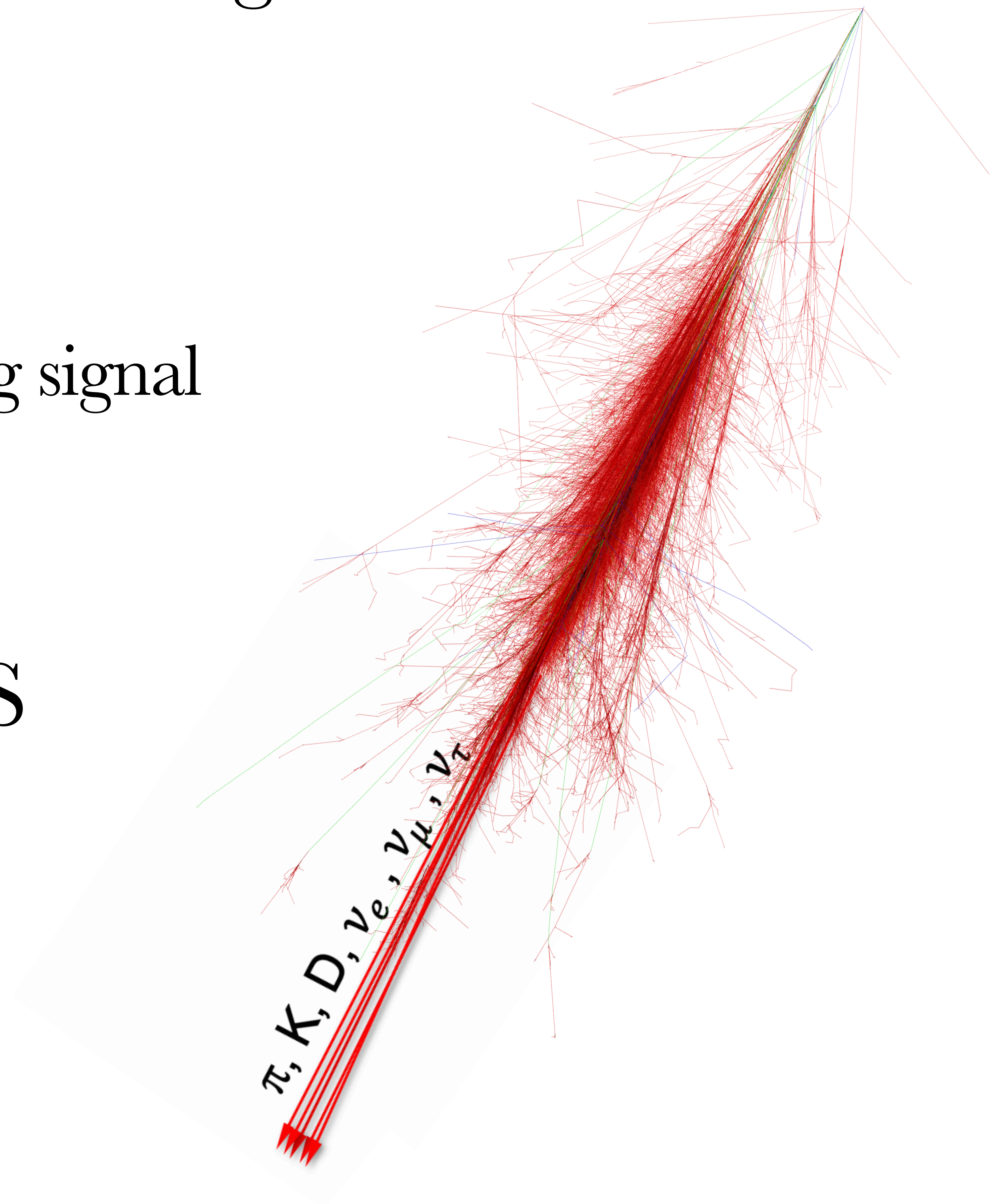
Astroparticle Physics and Dark Matter Searches at the FPF

Dark Matter Searches

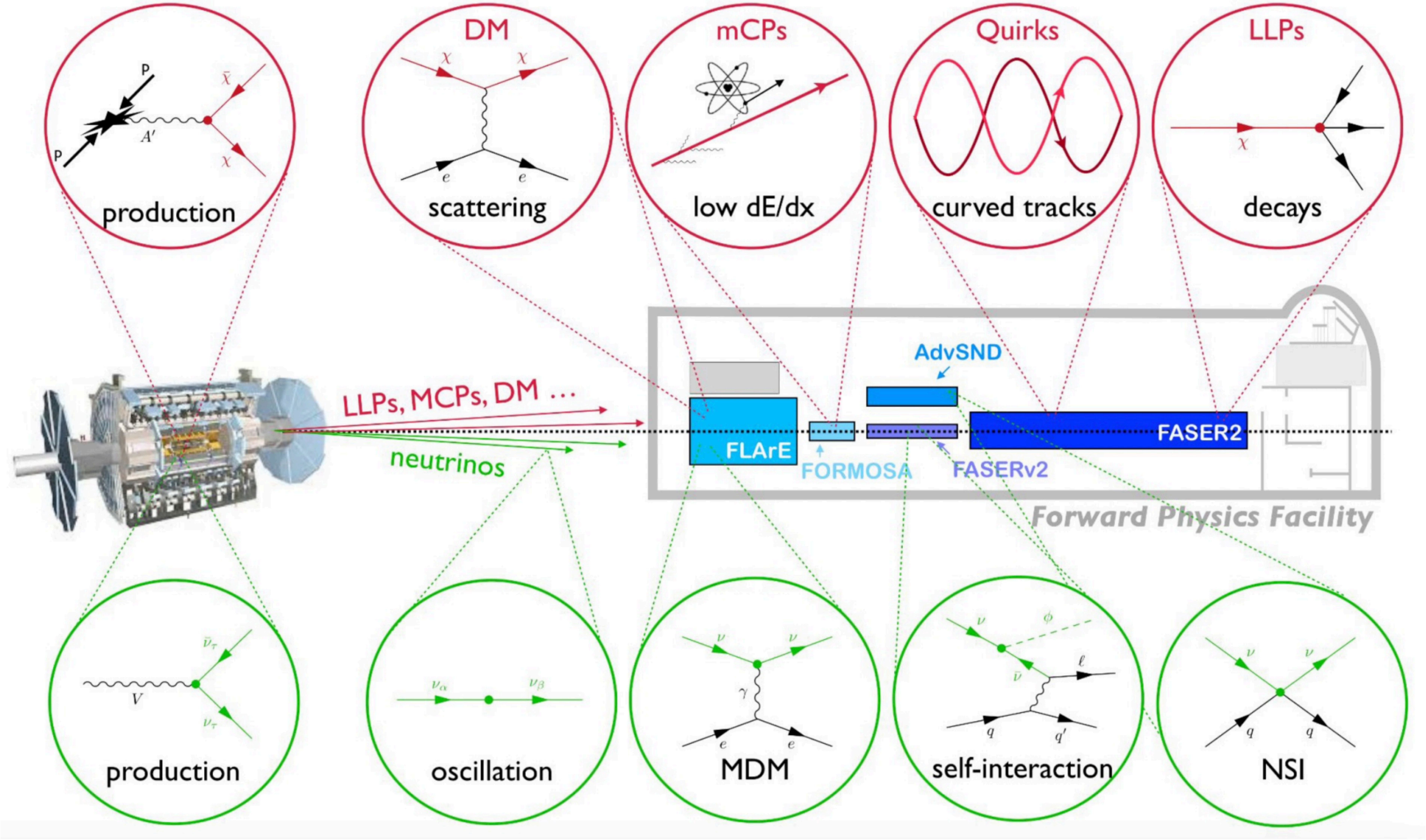
- BSM searches at the FPF towards understanding dark matter in the Universe
- Various BSM models can be tested:
  - Long-lived vector particles, e.g. dark photons, gauge bosons, …
  - Long-lived scalars, e.g. dark Higgs, two Higgs dublets, flavor-philic scalars, …
  - Long-lived fermions, e.g. sterile neutrinos, heavy neutral leptons, …
  - Other long-lived particles, e.g. axion-like particles, inelastic dark matter, …
  - Even more: Dark matter scattering, millicharged particles, Quirks, …
- In the ~~following~~ backup, a few example dark matter scenarios to be tested at the FPF
- For a complete description, please see FPF white paper…

Summary & Conclusions

- Understanding high-energy particle production in the forward region is an important aspect in astroparticle physics
  - Multi-particle production in extensive air showers (EAS)
  - The Muon Puzzle in EAS
  - Lepton fluxes in large-scale neutrino telescopes are both an interesting signal and background for astrophysical neutrino searches
  - Prompt atmospheric neutrino (muon) fluxes are of particular interest
- The FPF will help to understand lepton production in EAS
- Reduced associated uncertainties for astrophysical measurements, e.g.
  - Cosmic ray mass composition
  - Astrophysical neutrino searches
- Complementary constraints for indirect dark matter searches from the FPF



Summary & Conclusions



FPF Short Paper:
arXiv:2109.10905

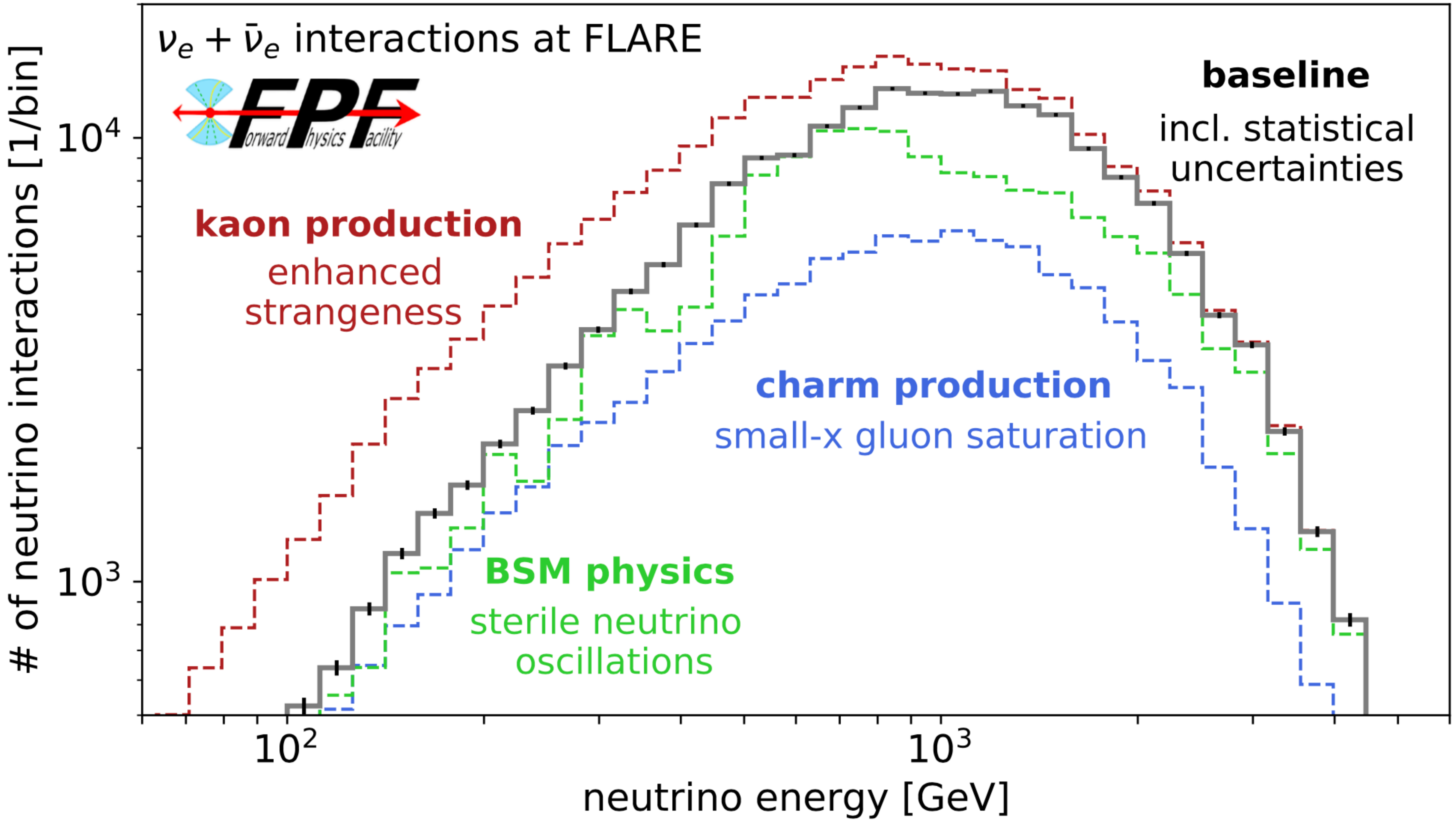
FPF White Paper:
arXiv:2203.05090

Thank you!

Karlsruher Institut für Technologie

Backup

Summary & Conclusions



FPF Short Paper:
arXiv:2109.10905

FPF White Paper:
arXiv:2203.05090

Thank you!

FPF Costs

Component	Cost Range	Comments
Facility Costs		
FPF civil construction	20-35 MCHF	Construction of shaft and cavern
FPF outfitting costs	7-15 MCHF	Electrical, safety, and other services
Total	**27-50 MCHF**	Total including integration
Int'l Experiment Costs		Labor, overhead, contingency not included
FASER2	17 MCHF	Non-US portion
FASERν2	16 MCHF	
ADV-SND	12 MCHF	
Total	**45 MCHF**	
US Experiment Costs		Labor, overhead, contingency included
FLArE	\$39-65 M	Contingency 40%
FORMOSA	\$7-8 M	Contingency 20%
FASER2	\$6-10.5 M	Contingency 50%, US portion
Total	**\$52-83.5 M**	

TABLE II. Cost ranges for components of the FPF and the experimental program. Costs of the infrastructure at CERN are Class 4 estimates according to international standards; they have a range (+50% and −30%). The costs for experimental components other than FLArE and FORMOSA are estimated as core costs, which consist of direct costs of materials and contracts only. The US costs include the costs for FLArE, FORMOSA, and portions of FASER2 appropriate for the US. The US costs include engineering and labor rates from either US laboratories or universities and include contingency (see text). Escalation over the construction period was added for US costs also. As described in the text the cost ranges result from technical or management choices that will be made in the future. All cost ranges are in FY2023 dollars.

FPF Costs

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033-34
(HL)-LHC nominal schedule	*Run3*	*Run3*	*Run3*	*Run3*	*LS3*	*LS3*	*LS3*	*Run4*	*Run4*	*Run4*	*Run4*	*LS4*
FPF/FLARE milestones		*Pre-CDR and physics proposal*	*R&D and detetor prototypes*	*CDR- long lead item magnet*	*Start of civil constr. TDR for detectors*	*Detector construction start*	*Long lead items for detector*	*End of civil constr. Install services*	*Detector install*	*Detector Commissioning and physics start*	*Physics running with full complement of detectors*	
US-DOE FLARE (kUS$)						9750	19500	19500	13000	3250		
US-DOE FORMOSA (kUS$)						800	1600	4000	1600			
US-DOE-FASER2 (kUS$)			875	1750	3500	2625	1750					
Total US-DOE (kUS$)			875	1750	3500	13175	22850	23500	14600	3250		

TABLE III. Proposed funding profile for the US DOE portion of the FPF experimental program using the upper ranges from Table II. The main components are FLArE, FORMOSA, and US contributions to FASER2. The estimates include all technical components and laboratory and university labor with appropriate overhead factors. The FLArE estimate has a 40% contingency applied, and the FORMOSA estimate has a 20% contingency applied. Cost numbers are in FY2023 dollars.

FASER

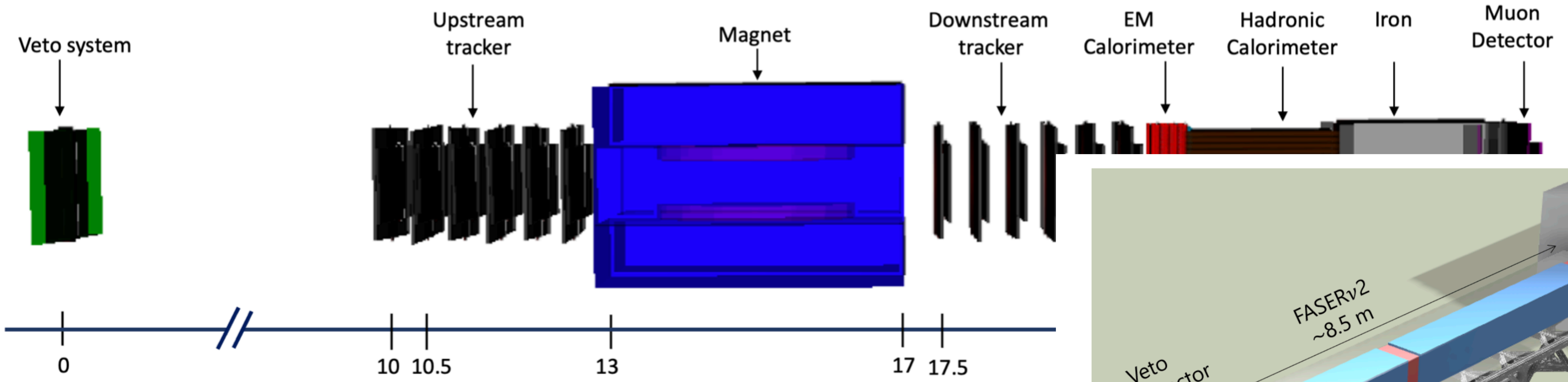


FIG. 10. Schematic diagram of the full FASER2 detector, showing the
decay volume, tracker, magnet, electromagnetic calorimeter, hadronic ca
detector.

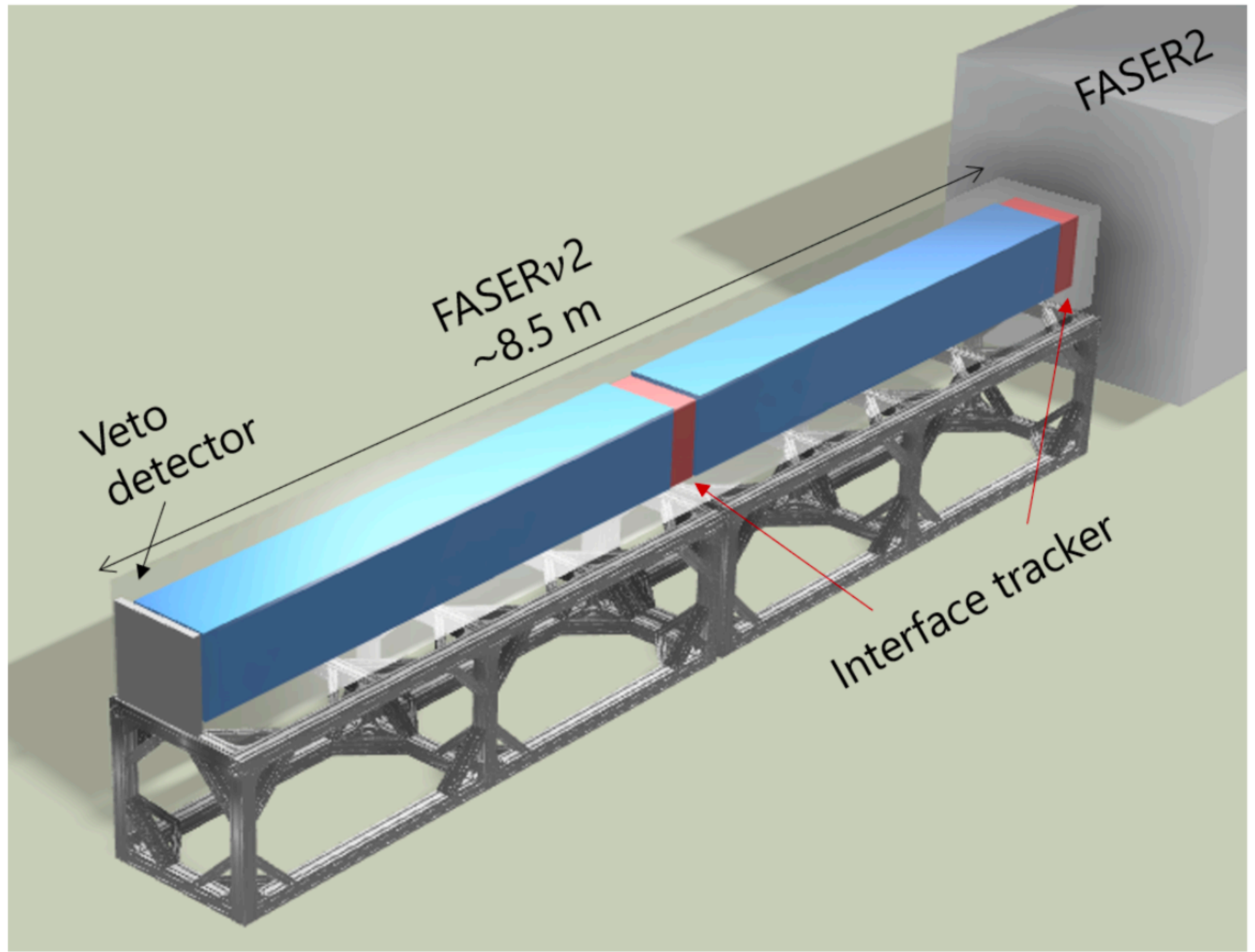


FIG. 11. Conceptual design of the FASERν2 detector.

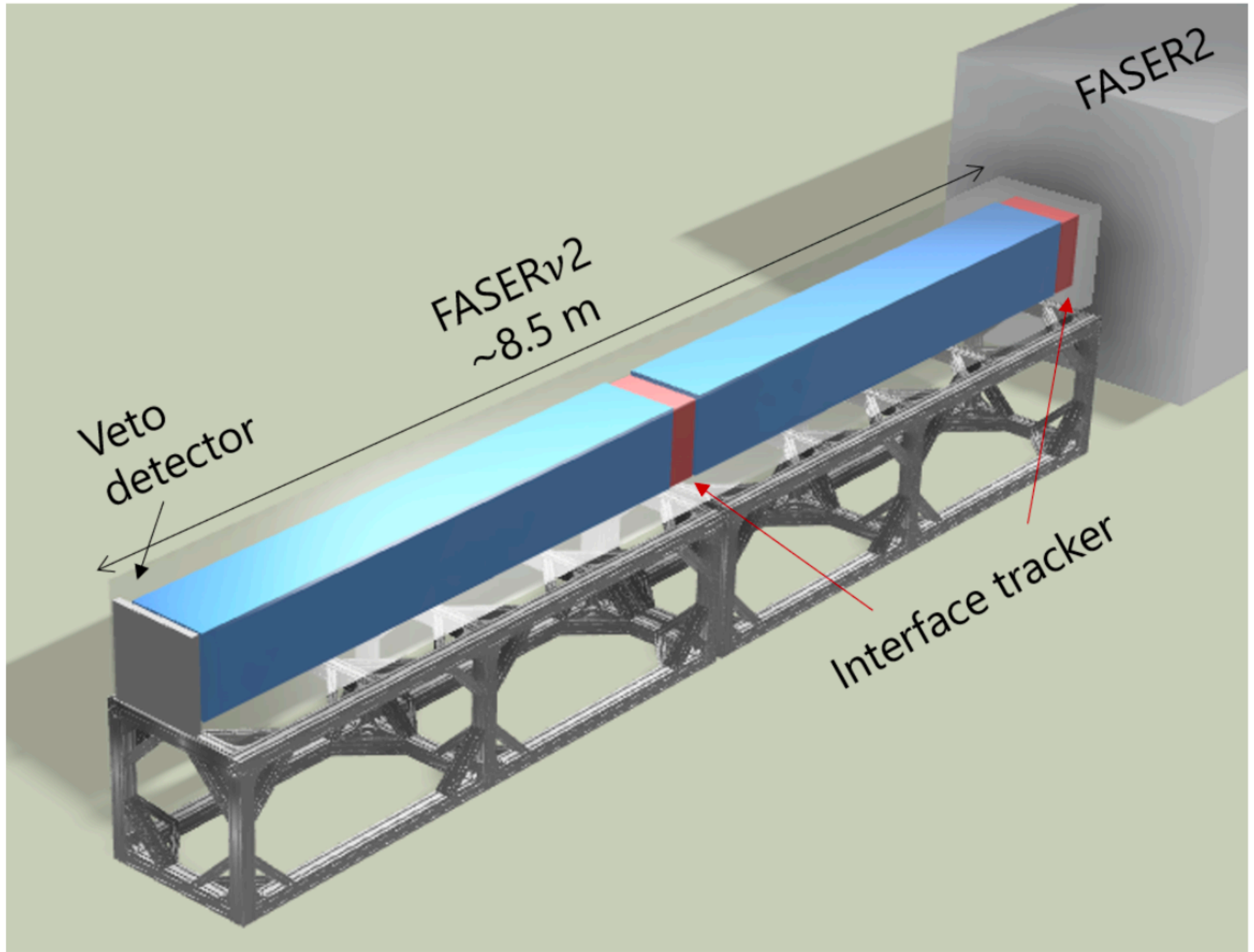


FIG. 11. Conceptual design of the FASERν2 detector.

AdvSND

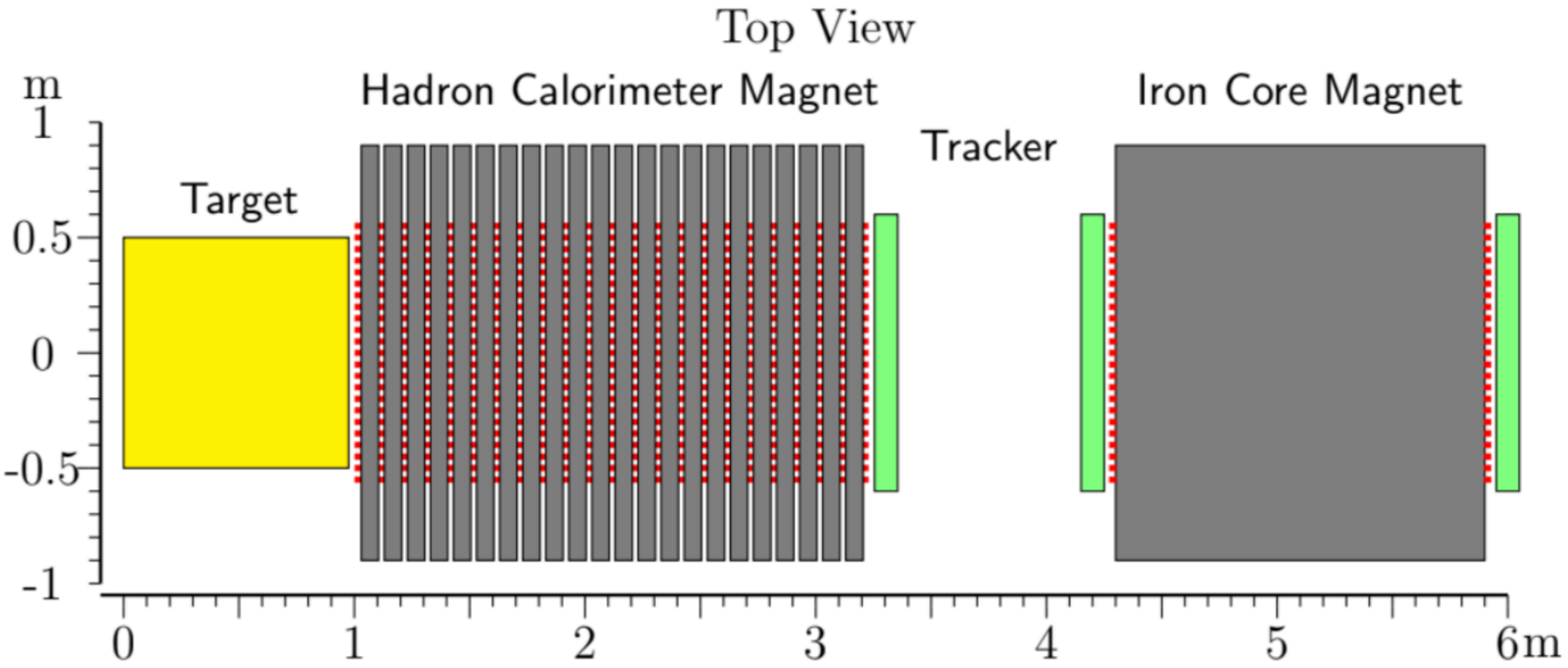


FIG. 12. Layout of the Advanced SND – FAR detector proposed for the FPF.

FLArE

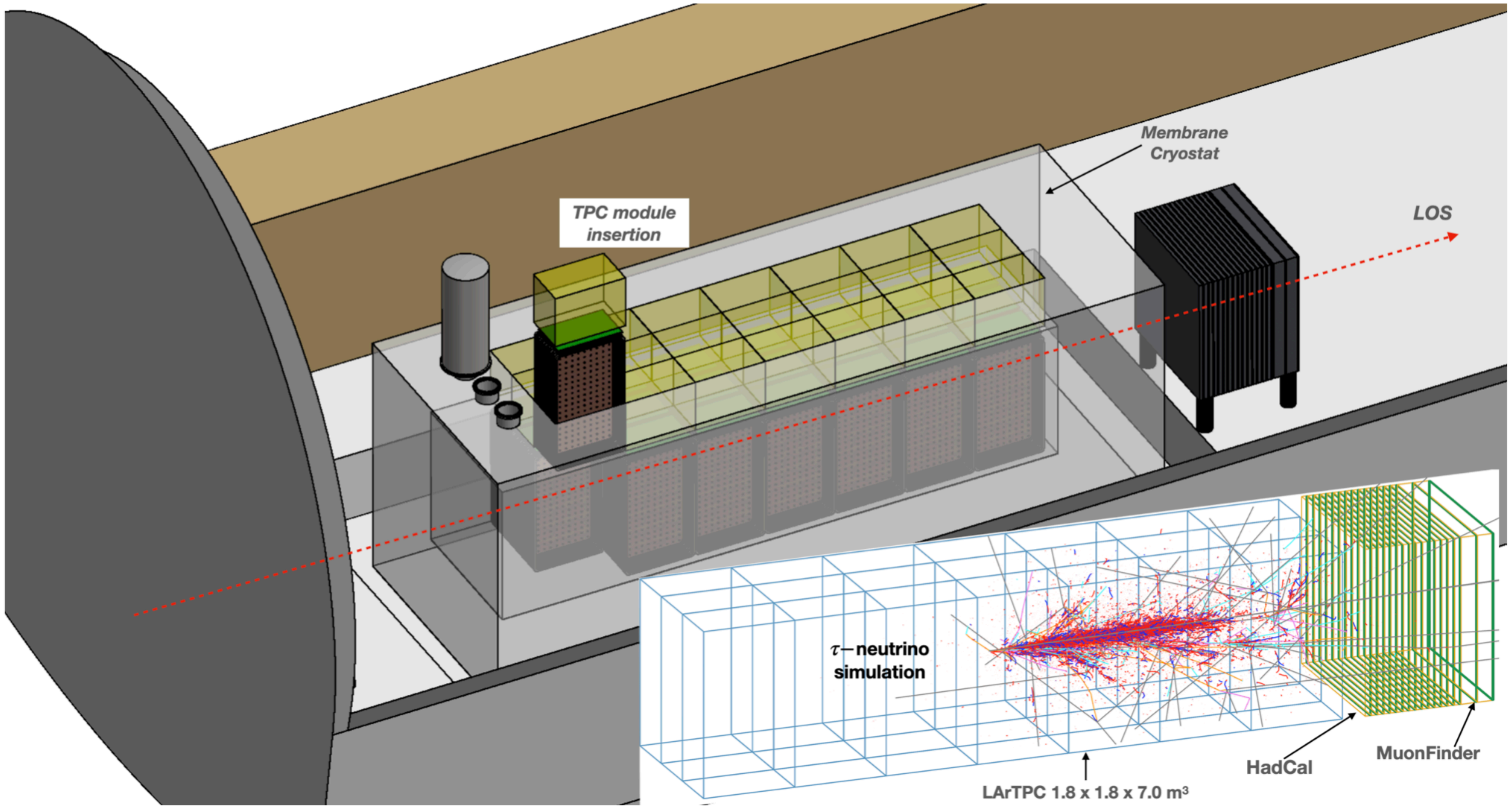


FIG. 13. Layout of FLArE detector in the FPF cavern with a simulated neutrino event inset. The detector is shown with an example of a TPC module being inserted from the top.

FORMOSA

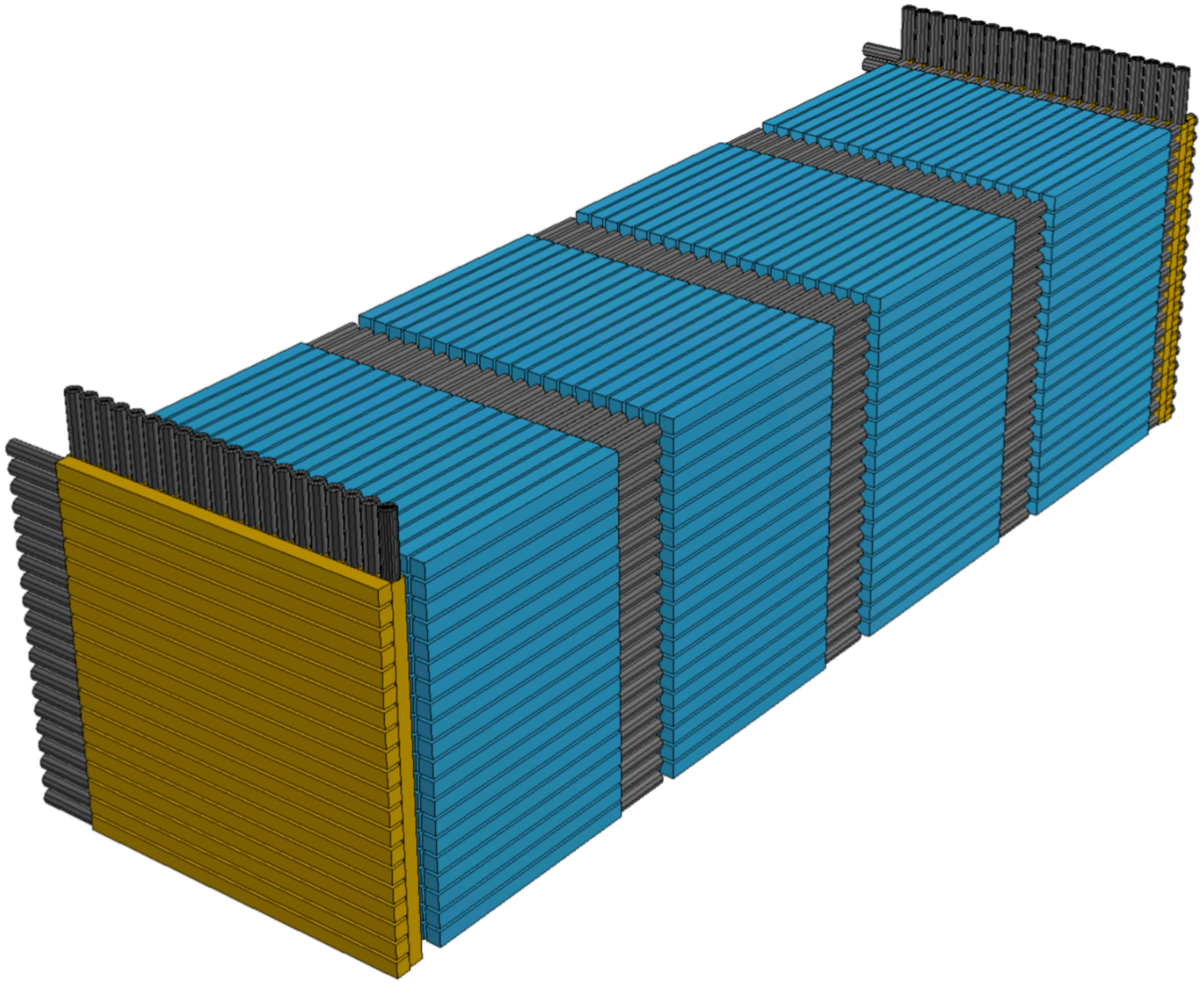


FIG. 14. A diagram of the FORMOSA detector components. The scintillator bars are shown in blue connected to PMTs in black.

Dark Matter Searches

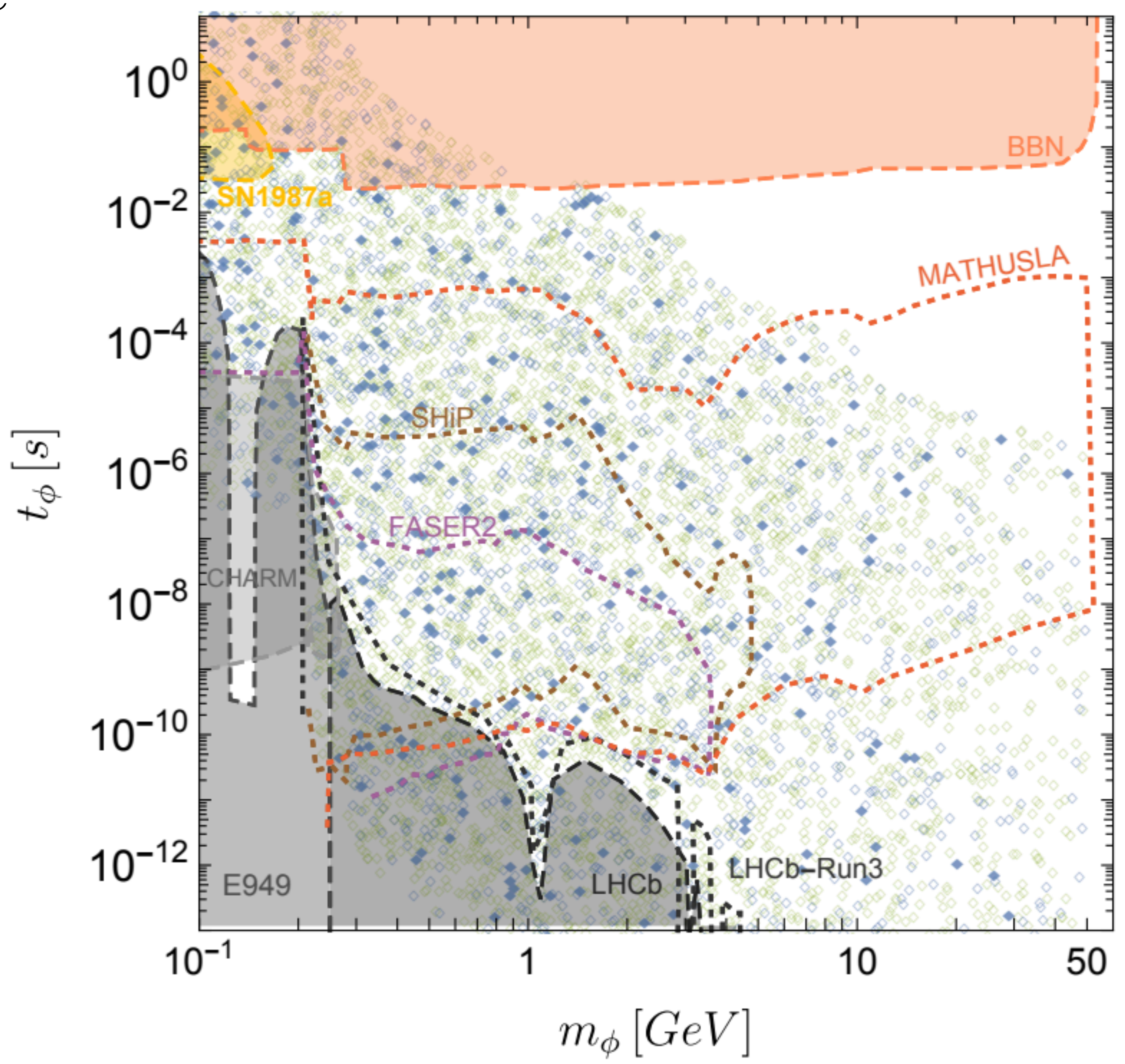
Example: Dark Matter from Freeze-In Semi-Production

- Interactions between the dark sector and the SM sector takes place through an additional mediator field, ϕ
- Semi-production, i.e. reaction of the dark matter candidate χ with the mediator ϕ:

$$\chi\phi \to \chi\chi$$

- Constraints on the mediator mass m_ϕ and lifetime t_ϕ
- For details of the model, please see A. Hryczuk, M. Laletin, JHEP 06 (2021)

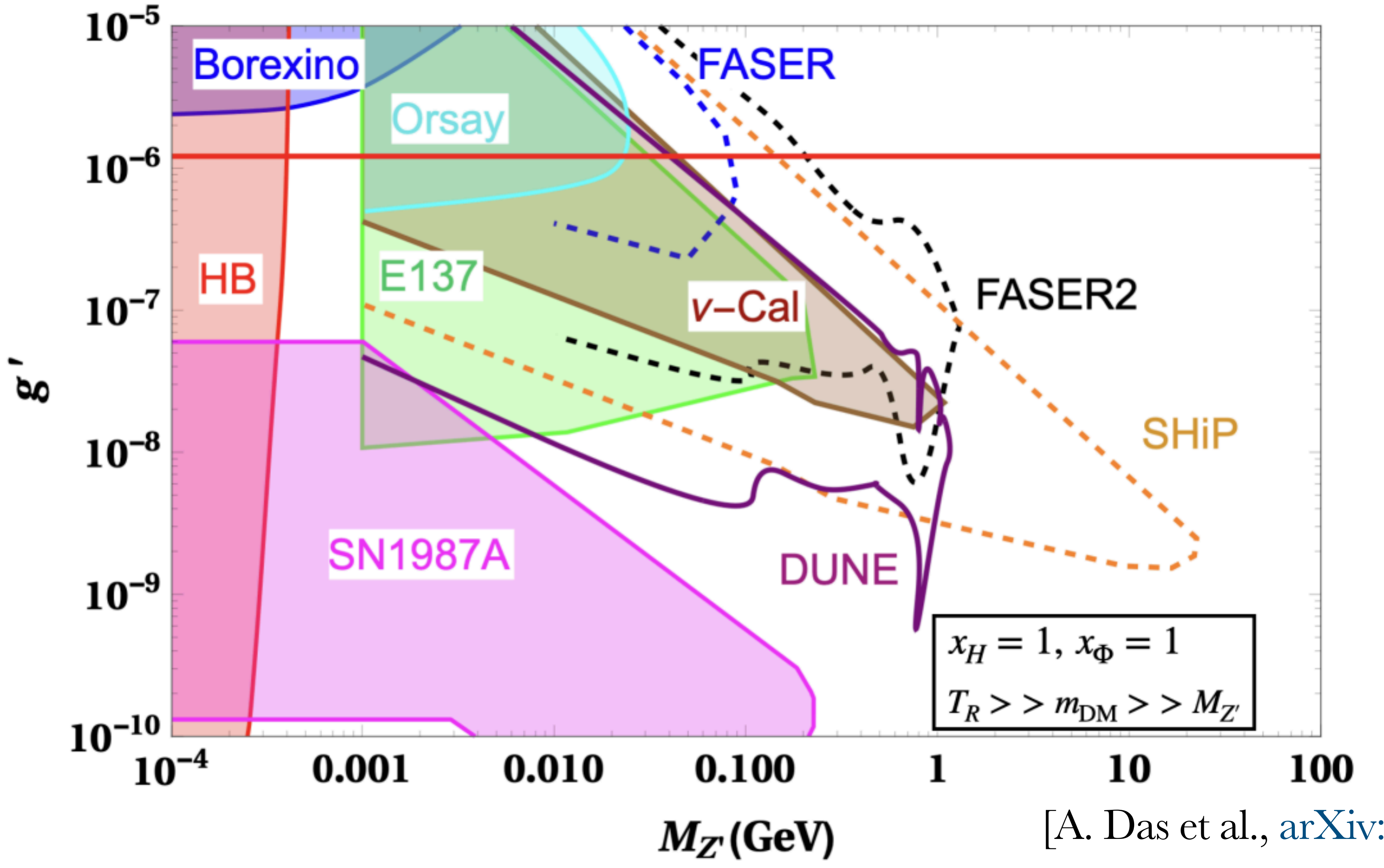
[A. Hryczuk, M. Laletin, JHEP 06 (2021)]

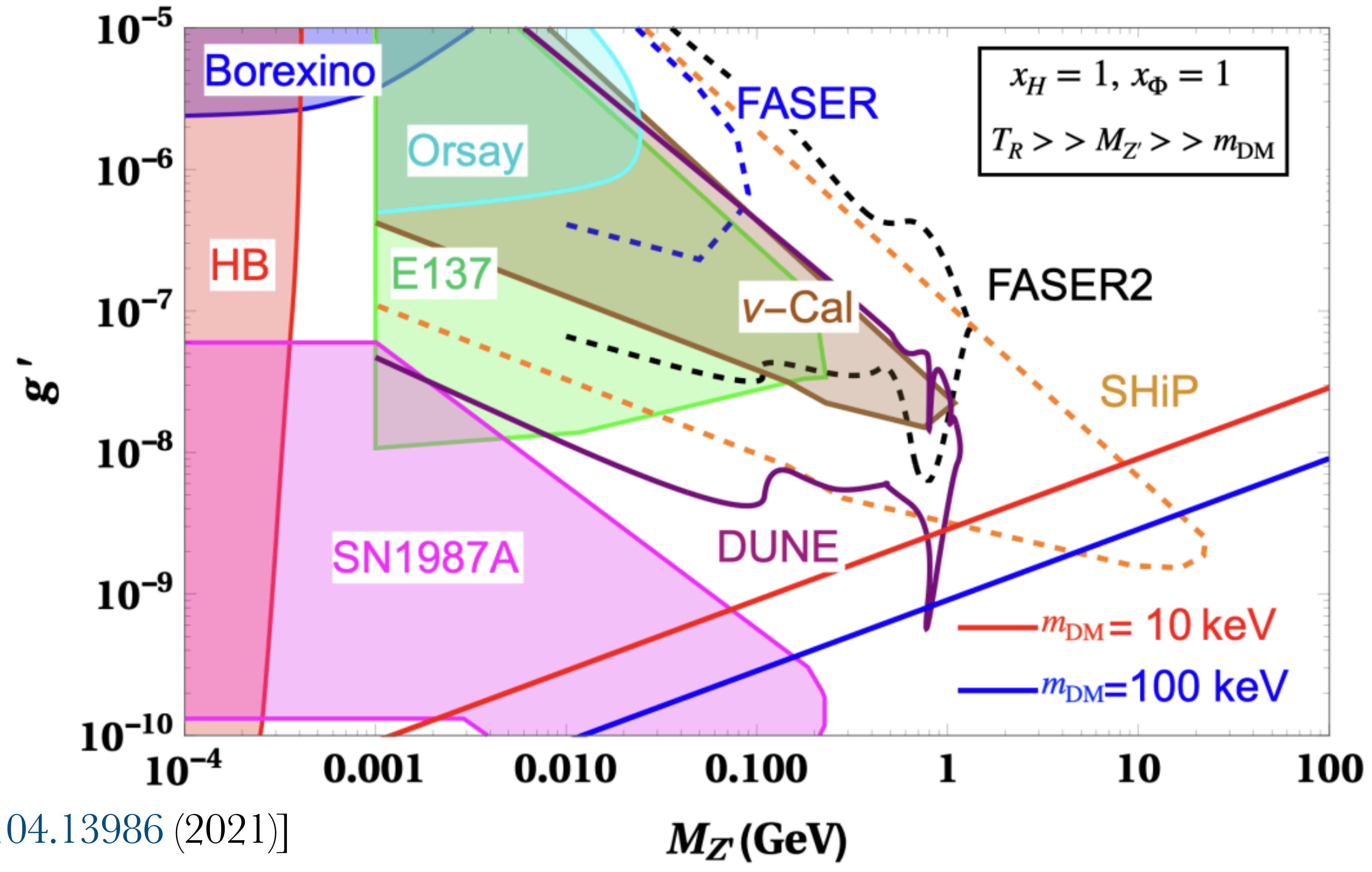


Dark Matter Searches

Example: Freeze-In Sterile Neutrino Dark Matter

- Inverse seesaw mechanism allows for mixing between light and heavy states
- $U(1)'$ extended framework: 3 SM singlet right-handed neutrinos and 3 gauge singlet Majorana fermions are introduced to generate the light neutrino mass
- Extra Z' which gets mass, $M_{Z'}$, when the $U(1)'$ symmetry is broken
- For details of the model, please see A. Das et al., arXiv:2104.13986 (2021)



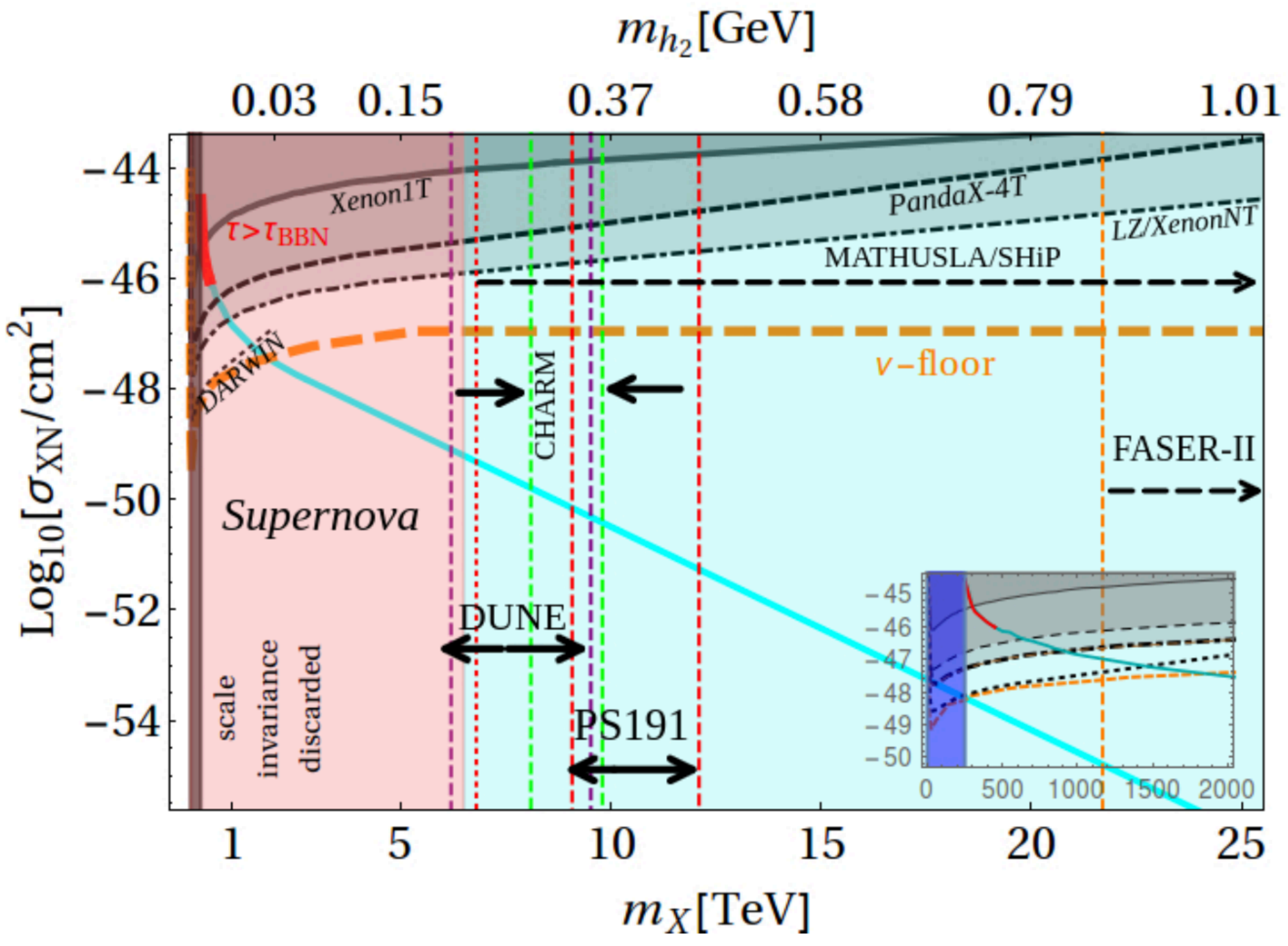


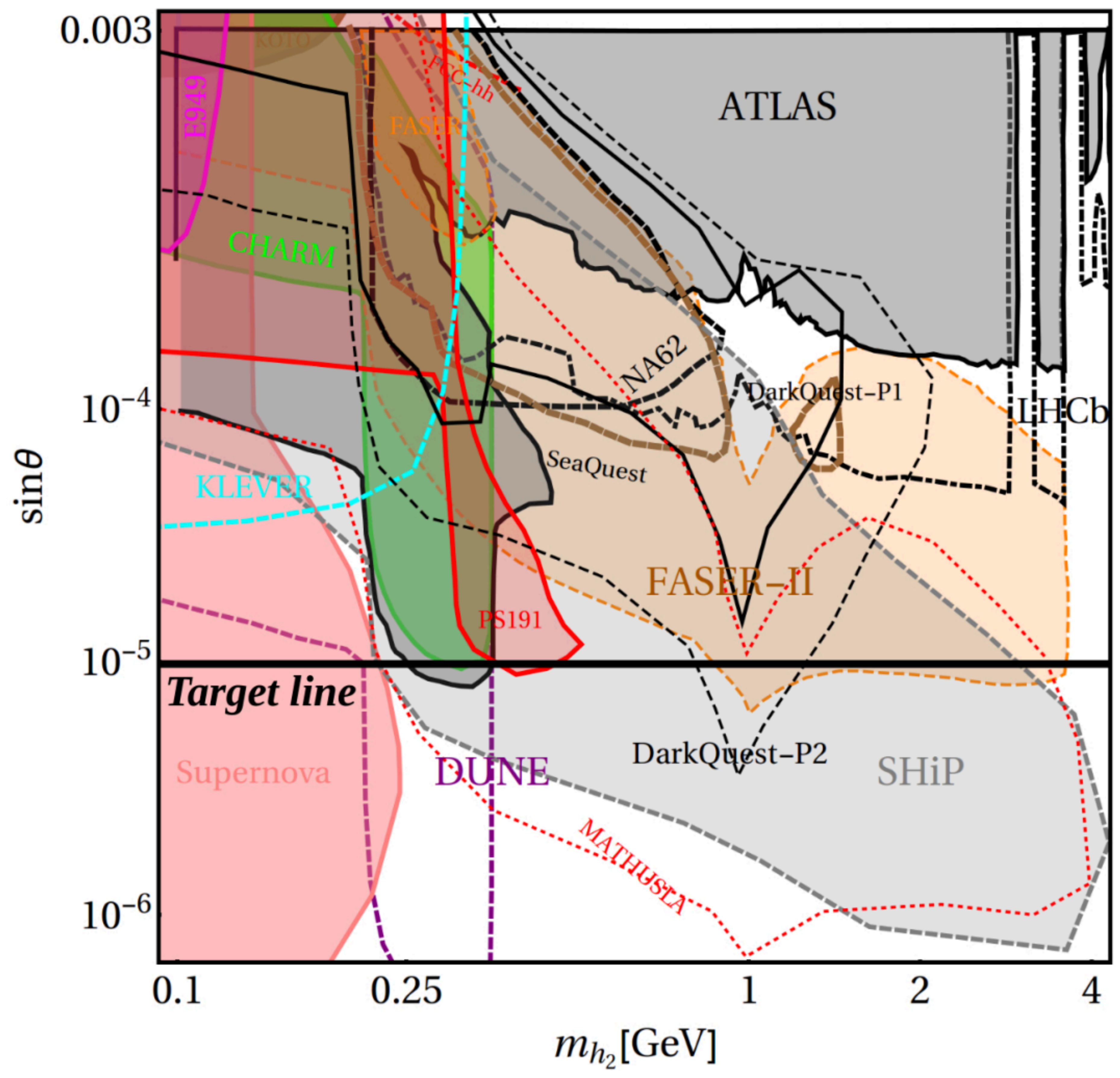
[A. Das et al., arXiv:2104.13986 (2021)]

Dark Matter Searches

Example: Imprints of Scale Invariance and Freeze-In Dark Matter

- Scale-invariant $U(1)_X$ extension of the SM with gauge boson X (dark matter particle)
- New gauge coupling g_X, dark matter mass m_X, and mixing angle θ





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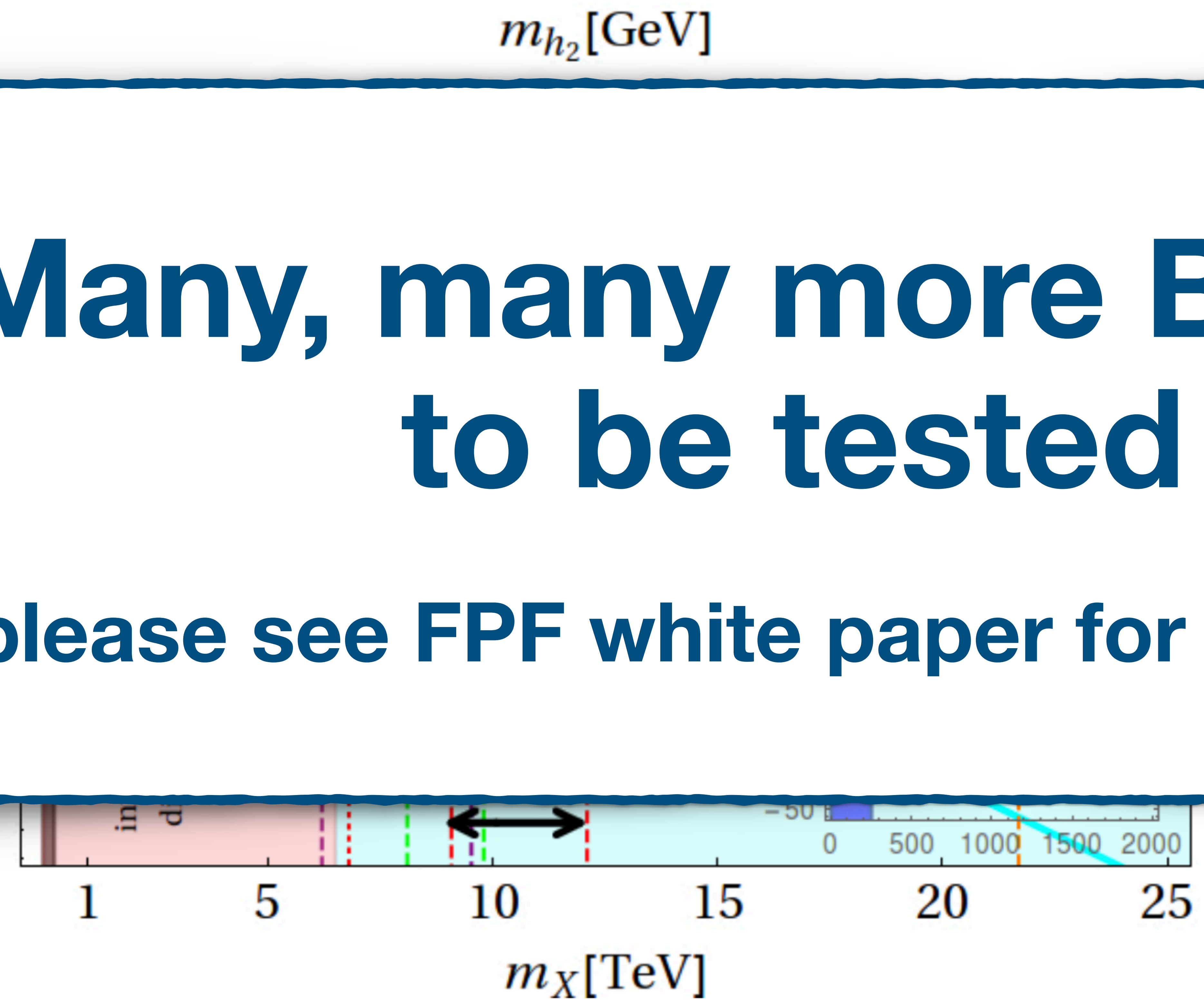
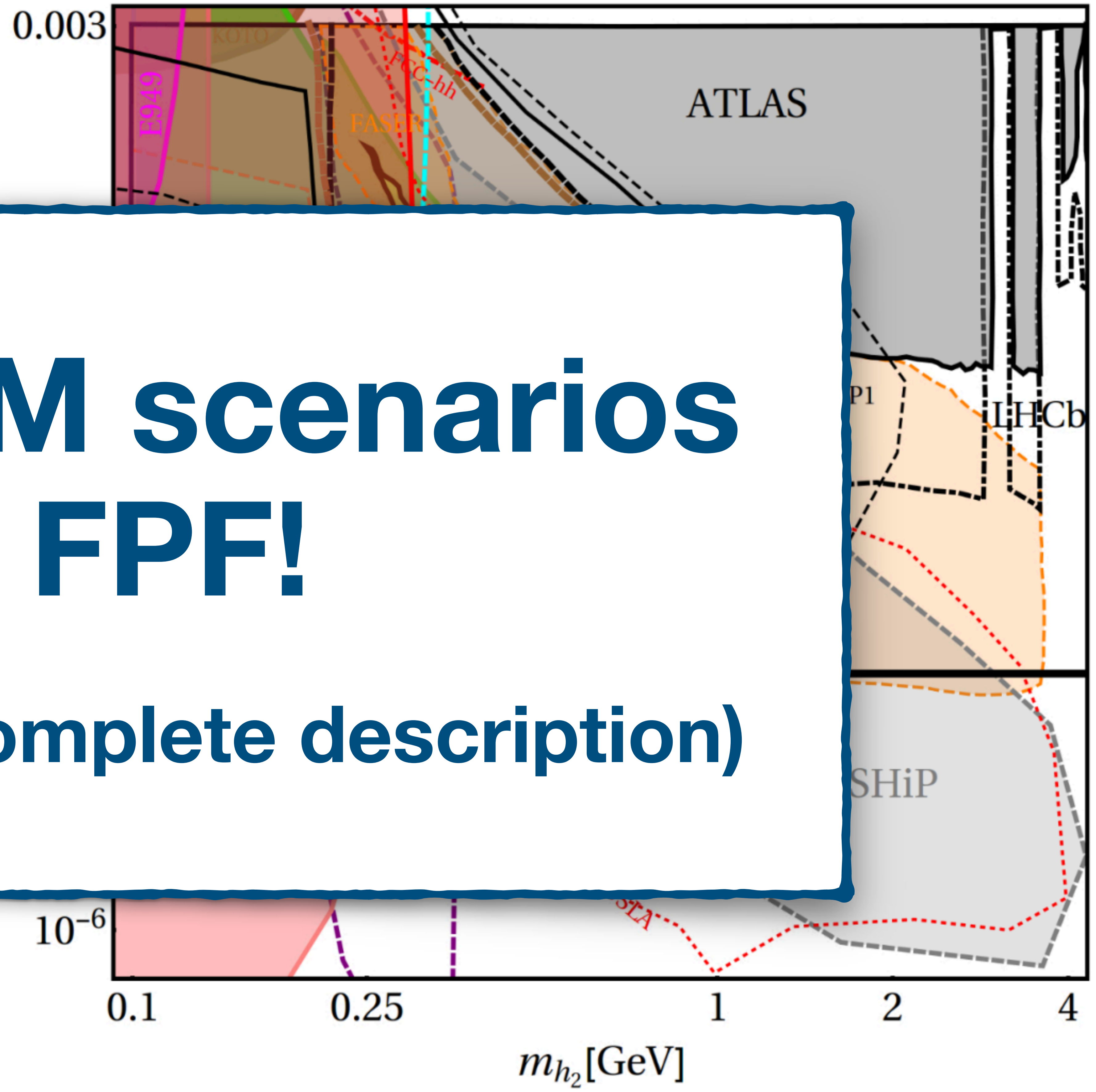
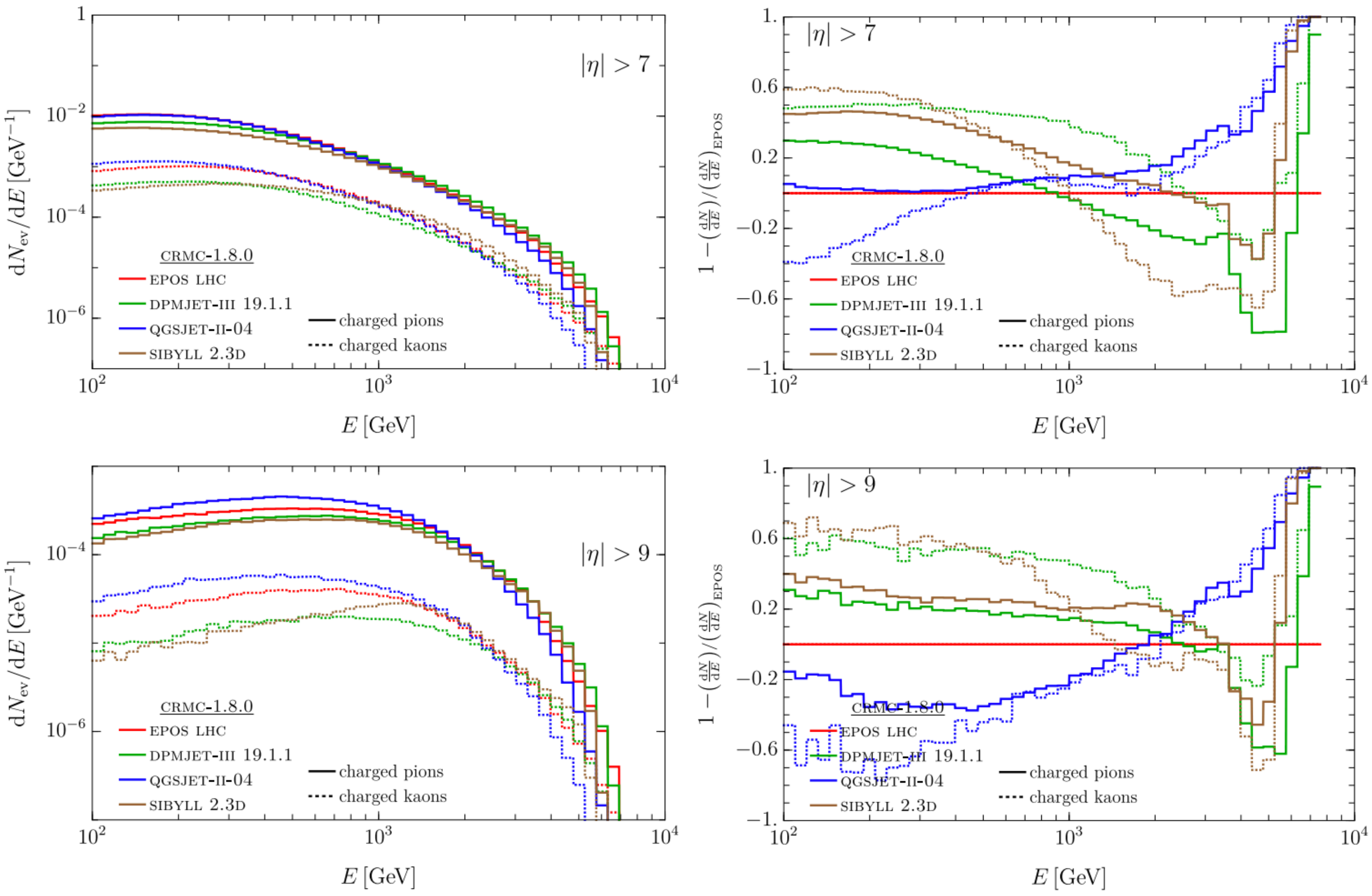




Many, many more BSM scenarios to be tested at FPF!

(please see FPF white paper for a complete description)

Light Hadron Production



Summary & Conclusions

- Further reading:
  - FPF Short Paper: Physics Reports 968 (2022), arXiv:2109.10905
  - FPF White Paper: Accepted by Journal of Physics G, arXiv:2203.05090
- If you want to become WG3 member, please sign up at:
  - https://docs.google.com/spreadsheets/d/1SKCB0uE_EX2sWJNPaJjPXg9xohsX6SqjDeUS-ypYICk/edit?usp=sharing
- If you have any further questions or input, please don't hesitate to contact us:
  - Jamie Boyd: jamie.boyd@cern.ch
  - Jonathan Feng: jlf@uci.edu
  - Felix Kling: flxkling@gmail.com
  - Mary Hall Reno: mary-hall-reno@uiowa.edu
  - Juan Rojo: j.rojo@vu.nl
  - Dennis Soldin: soldin@kit.edu

WG3 Organization

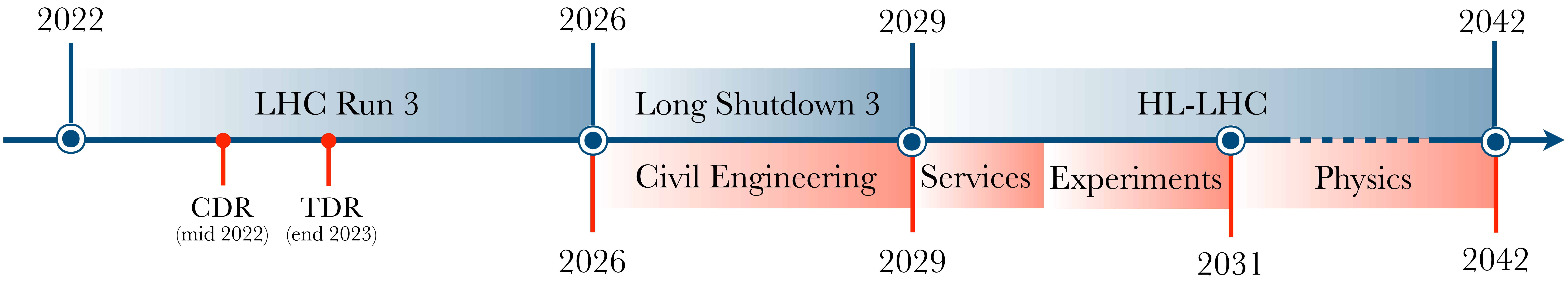
- First email to become part of WG3 on Oct. 19
- Sign-up sheet for WG3 members:
  - https://docs.google.com/spreadsheets/d/1SKCB0uE_EX2sWJNPaJjPXg9xohsX6SqjDeUS-ypYICk/edit?usp=sharing
- In the future, we will only contact members on this list!
- Please feel free to contact/add further interested candidates!

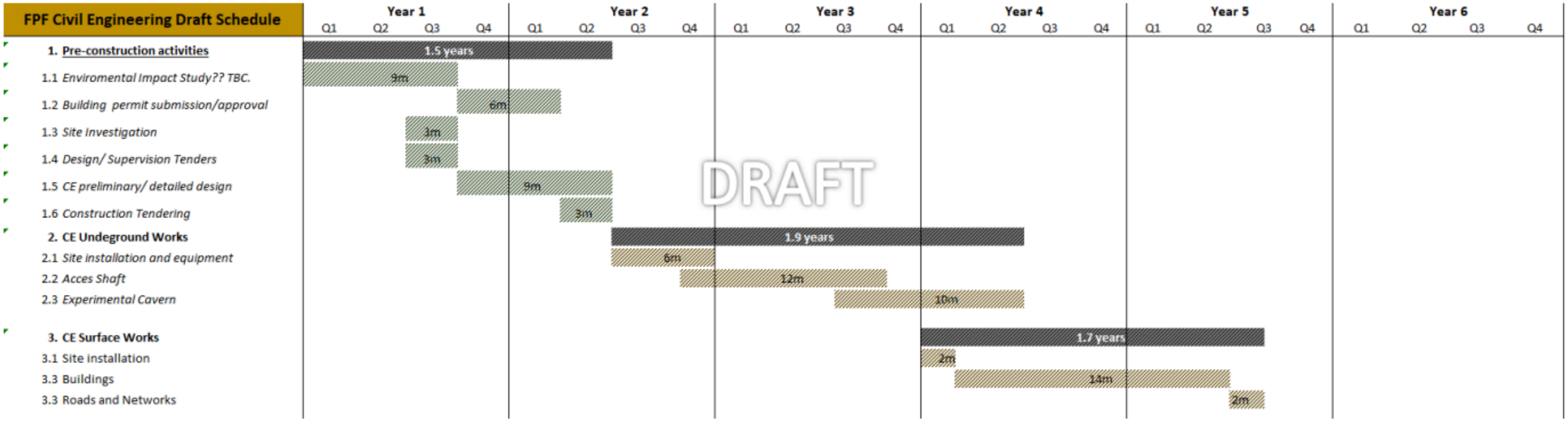
FPF Working Group "Light Hadron Production"

List of members of the FPF working group on light hadron production wich includes all topics that are related to forward pion/kaon production, e.g. non-perturbative physics, hadronic interaction models, cosmic rays, the cosmic muon puzzle, etc.

	First Name	Last Name	Affiliation	Email Address	Comments
1	Dennis	Soldin	Karlsruhe Institute of Technology	soldin@kit.edu	Working Group Lead
2	Luis	Anchordoqui	Lehman College, City University of New York	luis.anchordoqui@gmail.com	Working Group Lead
3	Felix	Riehn	Instituto Galego de Física de Altas Enerxías, USC, Spain	friehn@lip.pt	
4	Felix	Kling	DESY	felix.kling@desy.de	
5	Spencer	Klein	LBNL & UC Berkeley	srklein@lbl.gov	
6	Carlos	García Canal	Universidad Nacional de La Plata-IFLP CONICET	cgarciacanal@fisica.unlp.edu.ar	
7	Max	Fieg	UC Irvine	mfieg@uci.edu	
8	Hans	Dembinski	TU Dortmund	hans.dembinski@tu-dortmund.de	
9	Sergio	Sciutto	Universidad Nacional de La Plata - IFLP CONICET	sciutto@fisica.unlp.edu.ar	
10	Jorge	Fernandez Soriano	Lehman College, City University of New York	jorge.soriano@lehman.cuny.edu	
11	Laurie	Nevay	CERN	laurie.nevay@cern.ch	
12	Ralph	Engel	Karlsruhe Institute of Technology	ralph.engel@kit.edu	
13	Tanguy	Pierog	Karlsruhe Institute of Technology	tanguy.pierog@kit.edu	

FPF Timeline



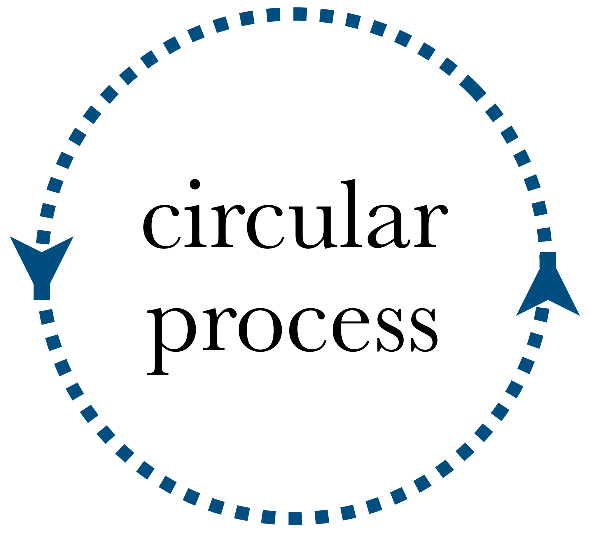


WG3 Goals

- <u>Short-term goals:</u>
  - Identify interested people and organize WG3 ✔
  - Define physics goals (✔)
  - Identify some action items (✔)
  - Finalize statement of scope and goals (✔)
    - Dennis & Luis will draft a first document to be circulated to WG3 for feedback
  - Assign volunteers (students?) to work on specific topics based on the existing simulations ✘
- Any open issues/questions will be discussed during the next WG3 meeting (Nov./Dec.)

WG3 Goals

- <u>Long-term goals (~February):</u>
  - Define analyses of FPF data that can help to understand light hadron production
  - Quantify how well we can test/constrain certain models/generators
  - Define detector requirements, e.g.
    - Rapidity ranges, e.g. $\eta > 7$
    - Energy resolution (i.e. low energy region)
    - Angular/spacial resolution
    - Requirements on flavor ID efficiency
    - …
  - Give feedback to experimentalists about detector requirements
  - Include realistic detector description in simulations



FPF Status

- FPF was discussed at the LHCC meeting last September:
  - From the LHCC minutes:

> "A proposal on the Forward Physics Facility (FPF), a large underground experimental facility, well shielded in the line of sight of the ATLAS interaction point, is being put forward. First informal discussions about the next steps with this proposal have taken place between the proponents and the LHCC chair."

> "Given the scope of the proposed facility and the scientific overlap with projects that fall into the responsibility of other committees, the LHCC proposes to discuss the FPF together with other proposals, in an appropriate forum such as the Physics Beyond Colliders study group, prior to moving towards reviews by the scientific committees to ensure a comprehensive and aligned view of the strategy for CERN moving forward. Considering the implications for the long-term scientific strategy and the future development of the CERN infrastructure, a discussion in the SPC may be appropriate to help define priorities prior to further steps."

  - Takeaway: FPF will be reviewed in conjunction with other proposals, particularly HIKE + SHADOWS and SHiP@ECN3, this year