UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES
Département de physique nucléaire et corpusculaire

Status and Prospects at CERN:

The FASER Experiment

on behalf of the FASER collaboration

FIPs Workshop October 2022 @ CERN

Claire Antel, Geneva University, 19th Oct 2022.

UNIVERSITÉ DE GENÈVE

FASER Overview

Location

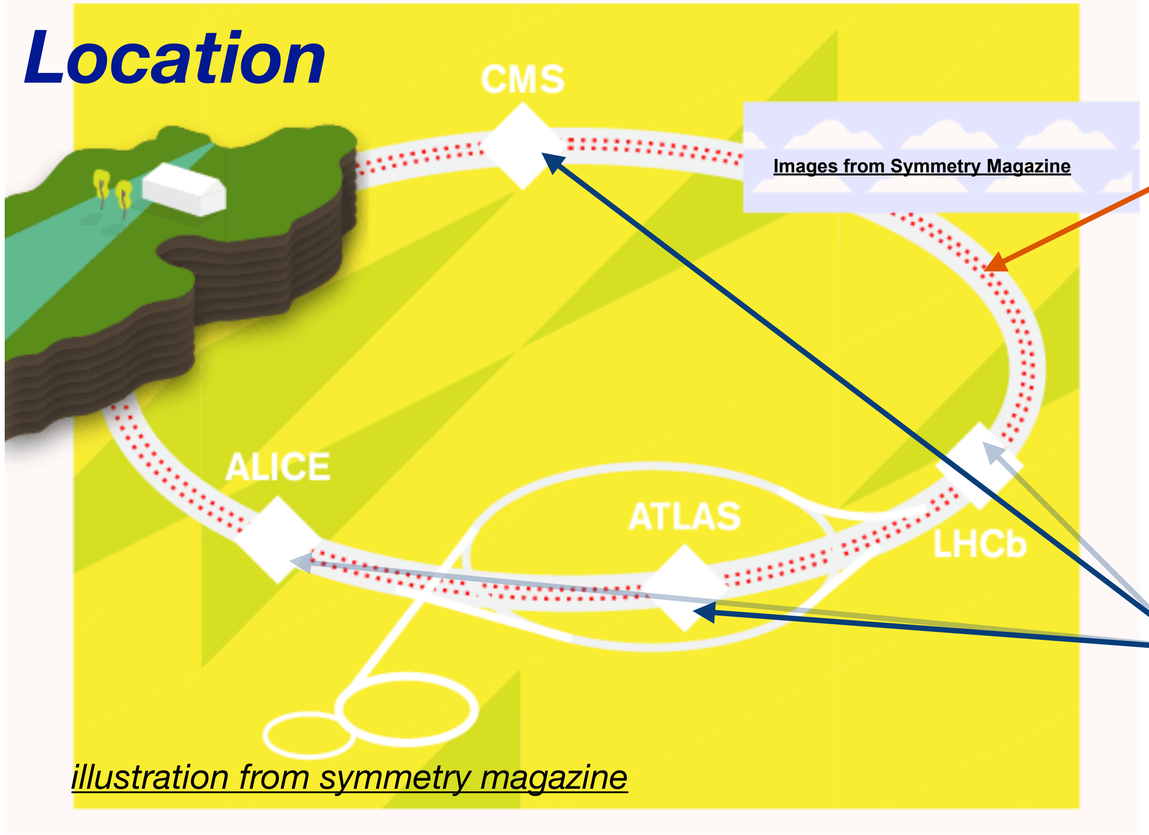
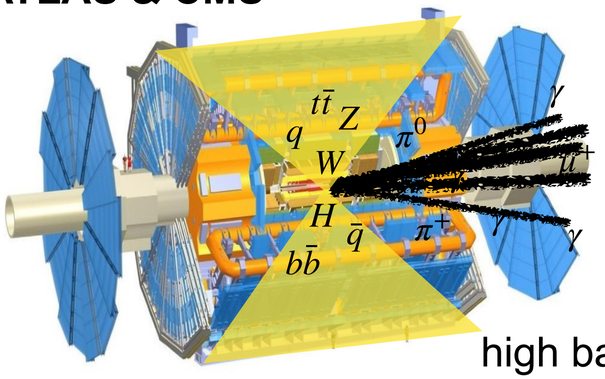


illustration from symmetry magazine

Large Hadron Collider, at HEP energy & intensity frontier.

4 titan detectors on ring;
The biggest, CMS & ATLAS, with wide physics agenda, ~$\mathcal{O}$(10s) meters in diameter & length, constructed directly at collision point

ATLAS & CMS



Focus on central/high pT, EW-scale coupling, since high background + not great sensitivity in very forward region

FASER Overview

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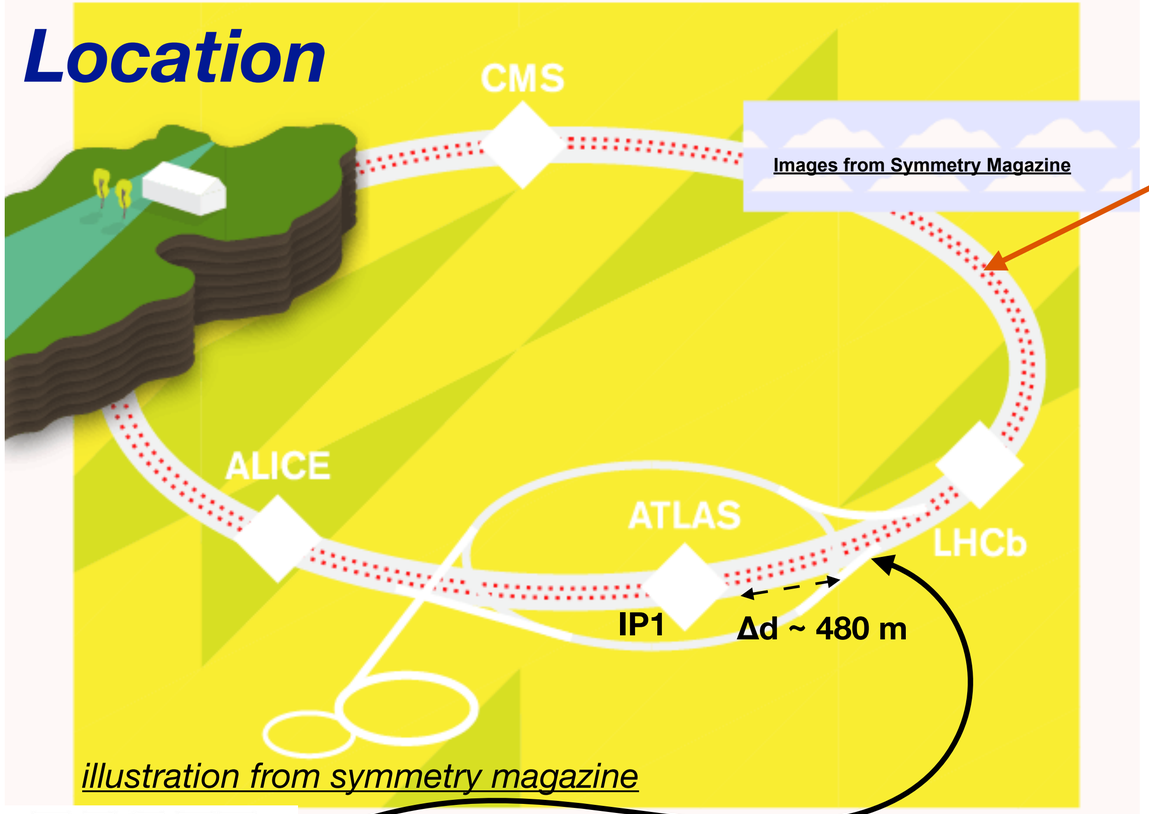

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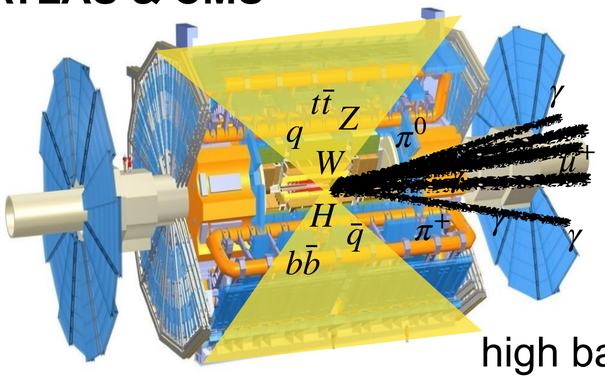

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FASER

(**F**orw**A**rd **S**earch **E**xpe**R**iment)

A new Run 3 small (20 cm diameter, ~ 7 m long) detector far from proton-proton collision point, but directly in line with beam pipe to ATLAS/IP1.

FASER Overview

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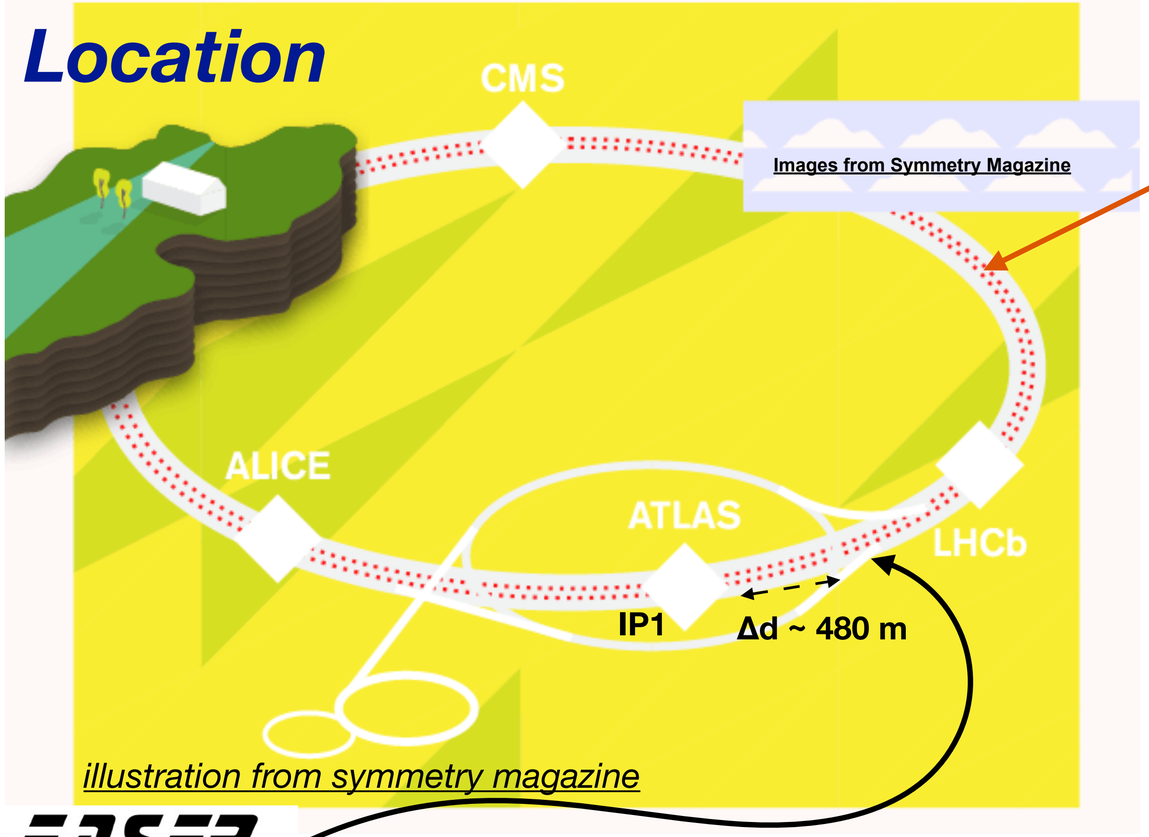

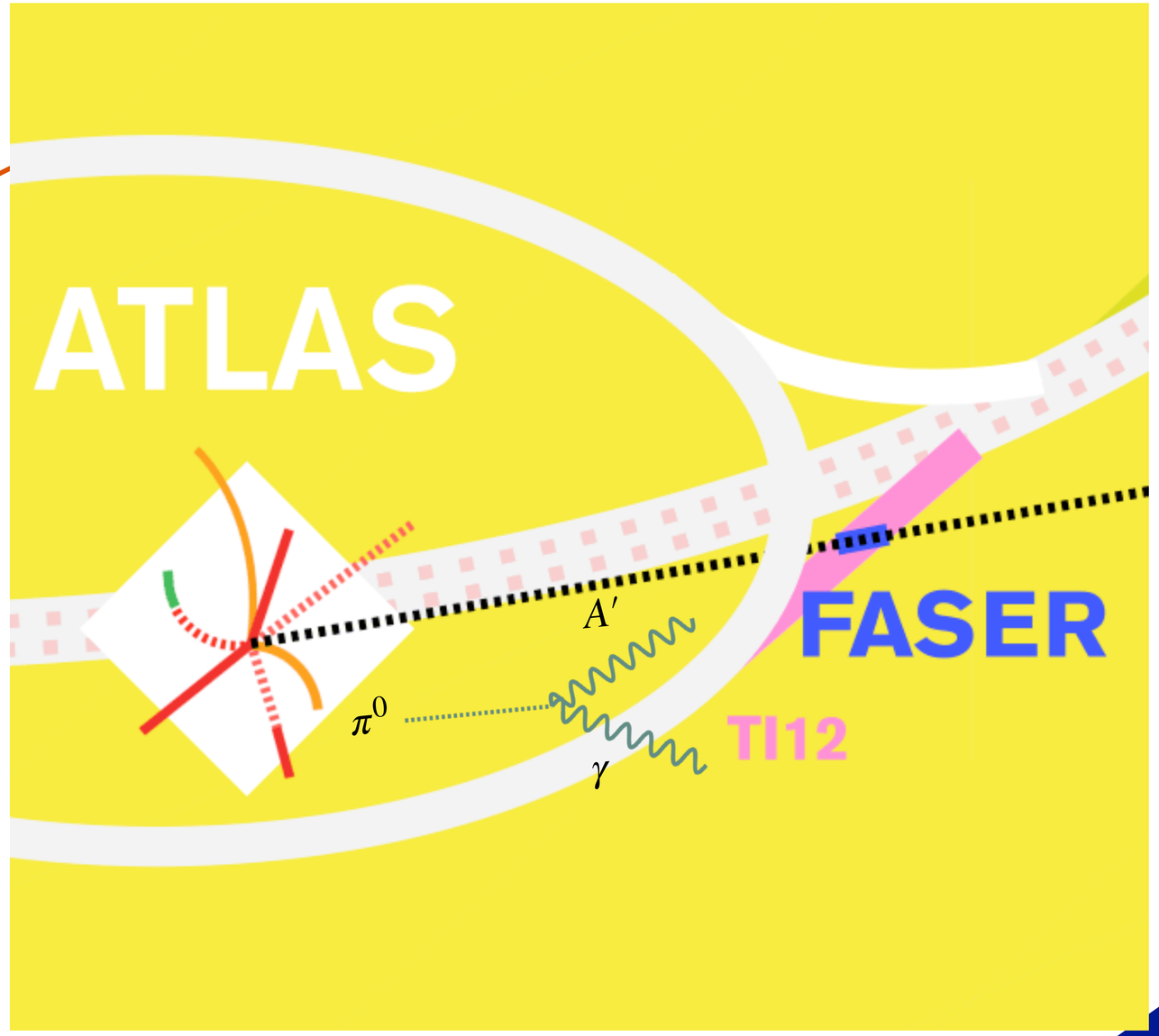

FASER

(**F**orw**A**rd **S**earch **E**xpe**R**iment)

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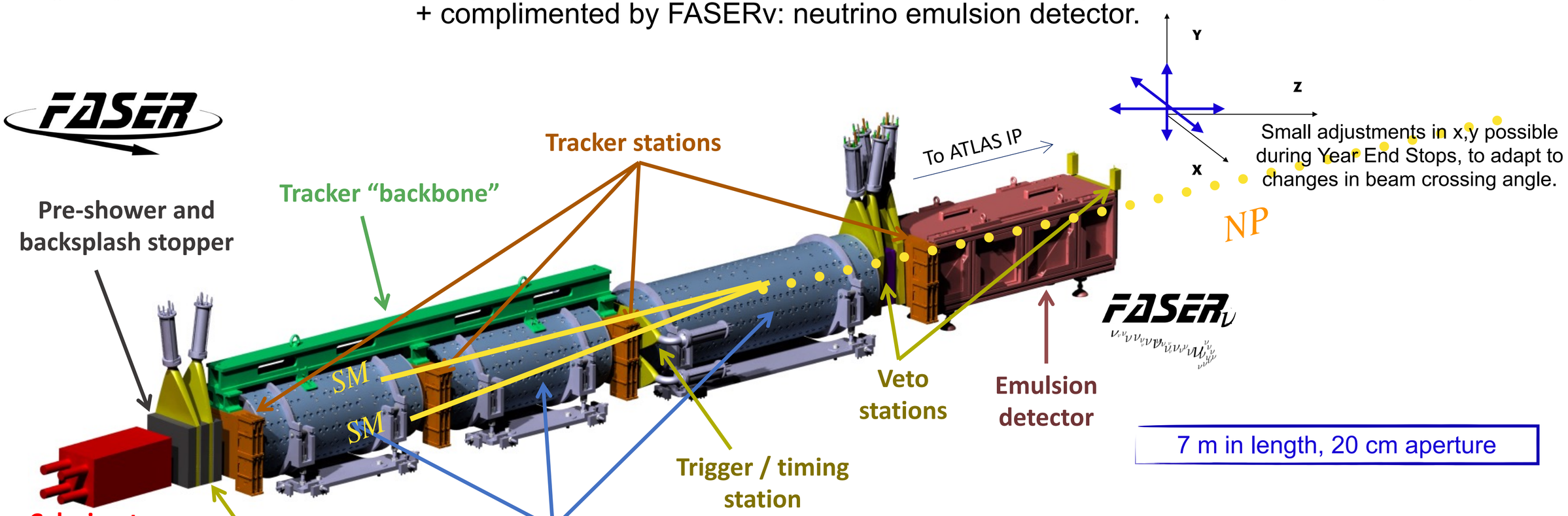
FASER Detector

- **Design** Cylindric in shape, to track/capture highly collimated Standard Model particle pairs from decay of long-lived particle, + complimented by FASERν: neutrino emulsion detector.



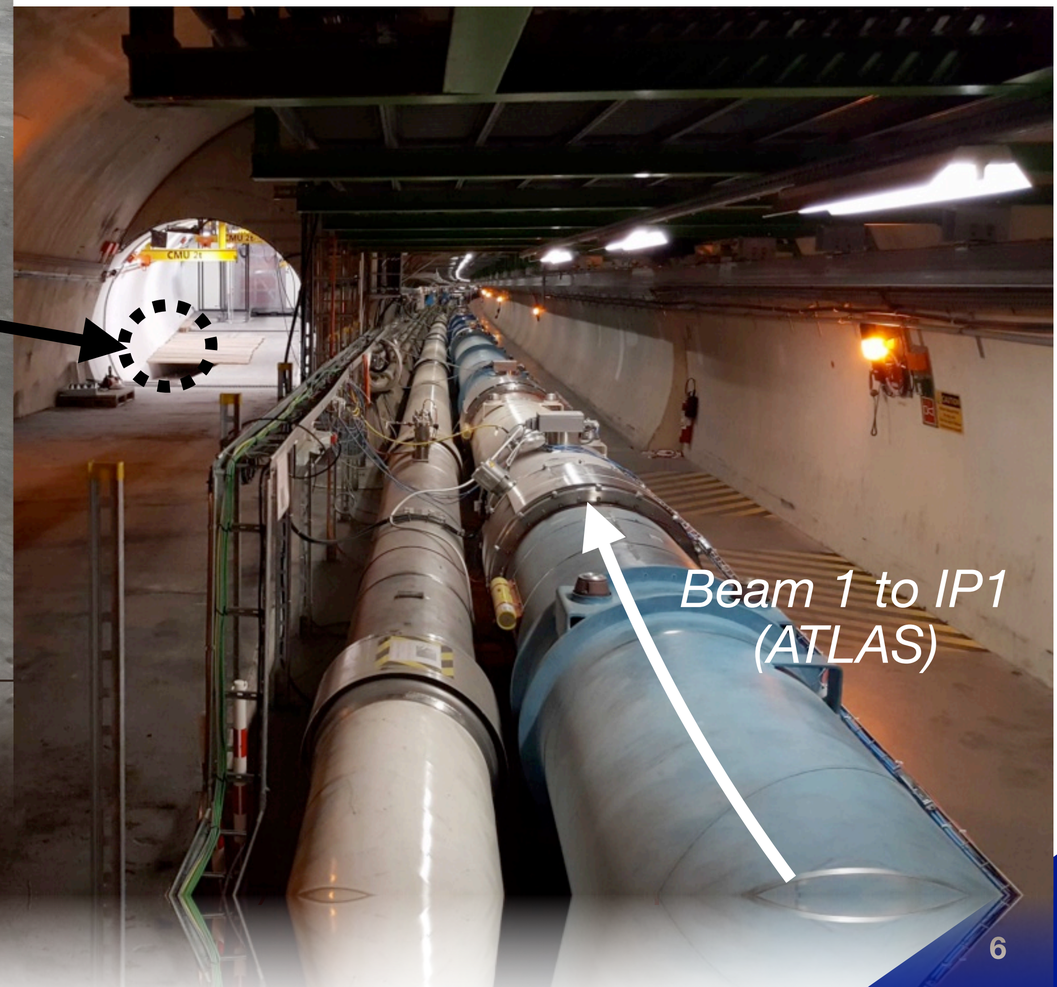
7 m in length, 20 cm aperture

Recycled parts (ATLAS SCTs for tracker, LHCb modules for calorimeter) —> low cost experiment.

Publications:

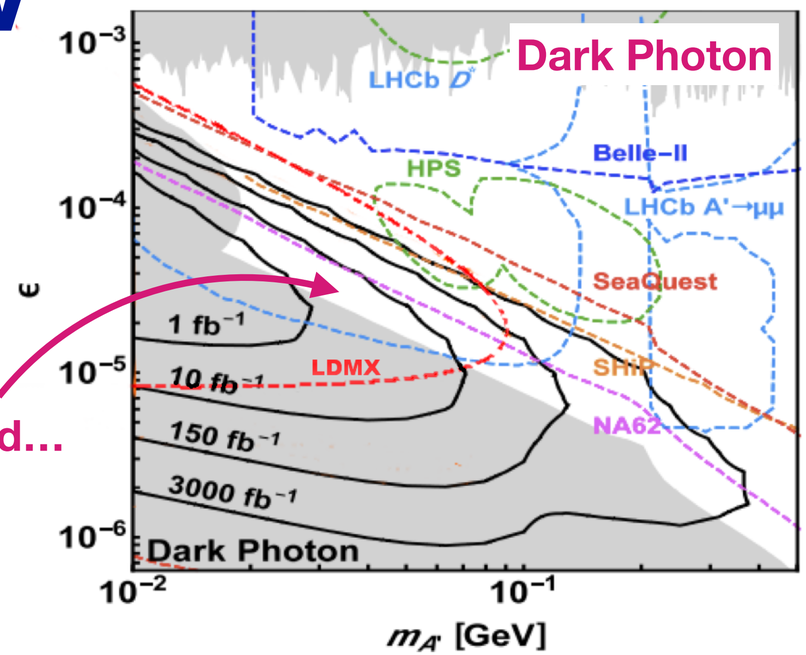
FASER Detector: arxiv: 2207.11427 FASER TDAQ: JINST 16 (2021) 12, P12028 FASER Tracker: NIMA 166825 (2022)

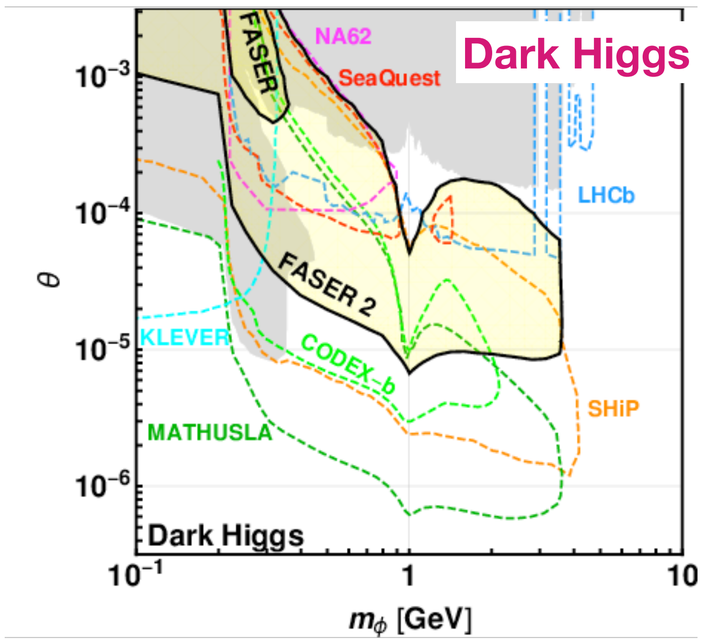
Actual FASER detector in actual tunnel.



FASER Overview

Physics Programme



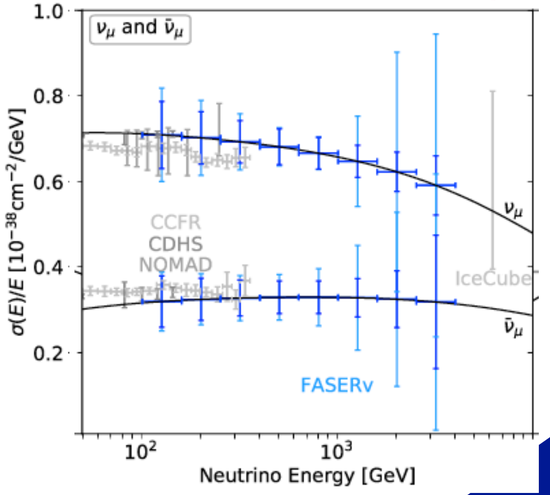


Already new ground with 10 fb^{-1} expected…

- **FASER (Run 3)** sensitive to unprobed phase space for dark photons, ALPs, Neutral Heavy Leptons, complimenting future results from NA62, LDMX, SeaQuest, HPS, Ship…
- **Future FASER 2 (HL-LHC)** (assumed 10x bigger) could probe further.
  - Sensitivity to New Physics via heavy meson production (e.g. dark Higgs); Larger angle to beam axis.

- **FASERv (Run 3)** to study Standard Model neutrino interactions for formerly uncovered energy ranges.

FASERv: ν_μ estimated ν-nucleon CC cross section sensitivity



FASER Construction & Commissioning

A snapshot

The challenge: Short time scale!

2017 — Concept born

ForwArd Search ExpeRiment at the LHC

Jonathan L. Feng,[1,*] Iftah Galon,[1,†] Felix Kling,[1,‡] and Sebastian Trojanowski[1,2,§]
[1]*Department of Physics and Astronomy, University of California, Irvine, California 92697-4575, USA*
[2]*National Centre for Nuclear Research, Hoża 69, 00-681 Warsaw, Poland*

(Received 13 October 2017; published 5 February 2018)

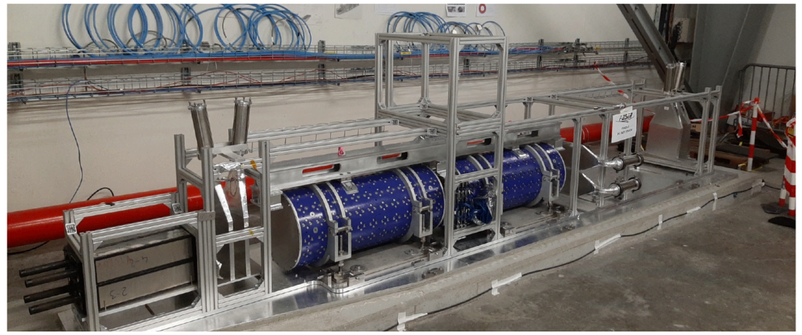
2019 March — FASER approved

~~2020~~ 2021 March — FASER installed

Delay due to COVID-19 pandemic

~~2021~~ 2022 March — Start of Run 3

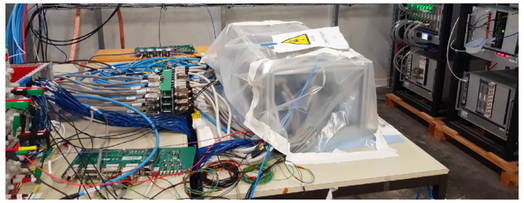
Civil engineering (2019)



Dry assembly above surface (end 2020)

Installation in tunnel (March 2021)

Cosmic-Ray stand:
FASER Scintillators + tracker planes (Summer 2020)



Trigger	Rate (Hz)
Veto scintillator station	3.5
Timing scintillator station	10
Pre-shower scintillator station	0.25
Calorimeter	0.25
Random	1
Total rate	15

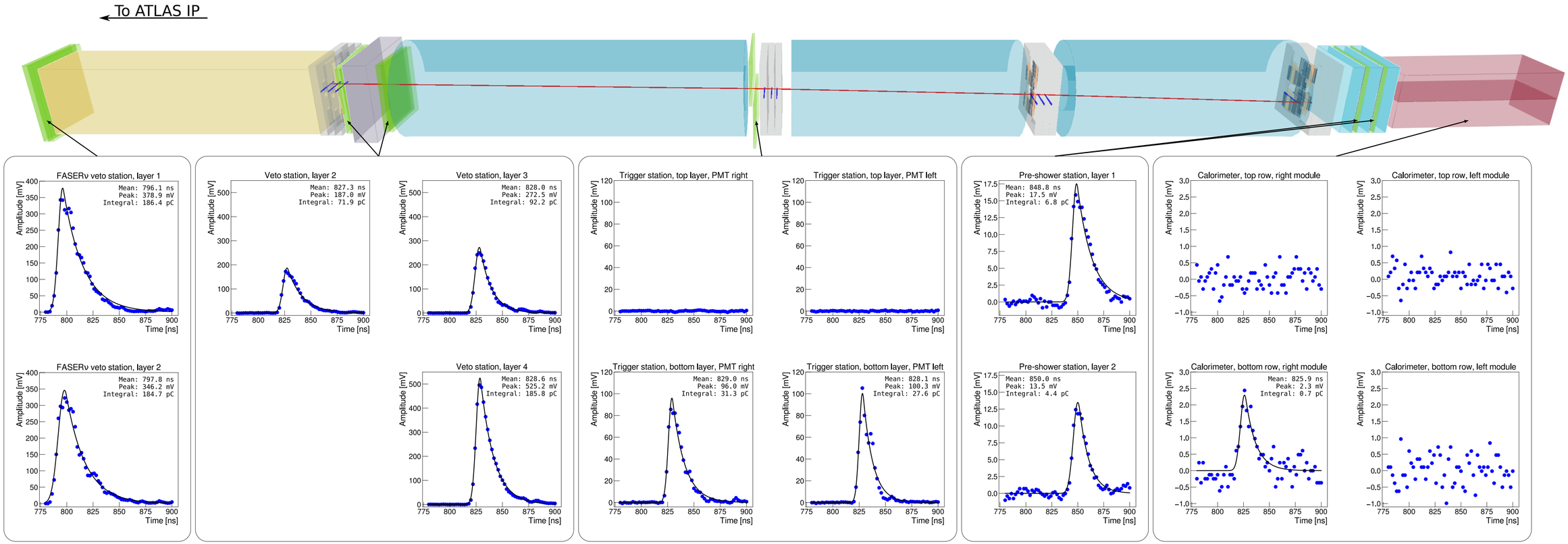
2021 in tunnel: 125 Million cosmic ray/noise induced events collected

First data from 13.6 TeV proton collisions

Event Display

Run 8336
Event 1477982
2022-08-23 01:46:15

Early collision data let us time tune in detector
(1/2 proton bunch-crossing precision)

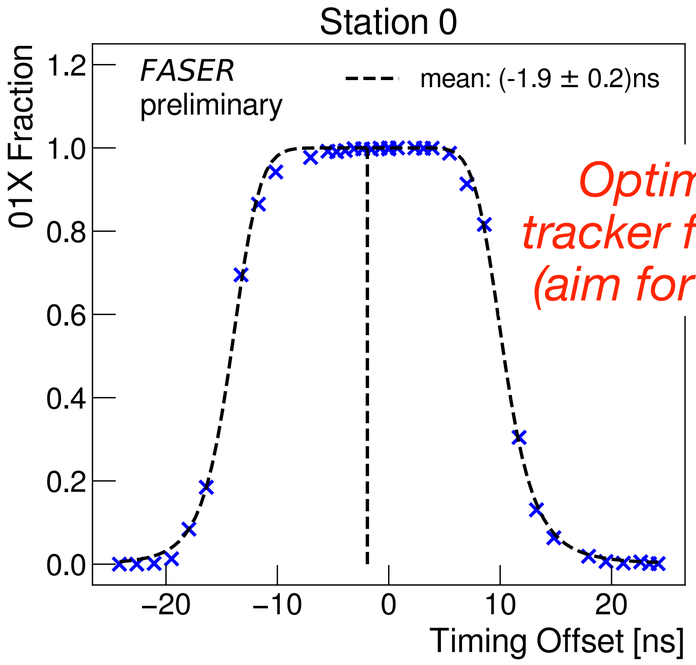


Now well timed in for triggering on charged particles passing through front to back of FASER.

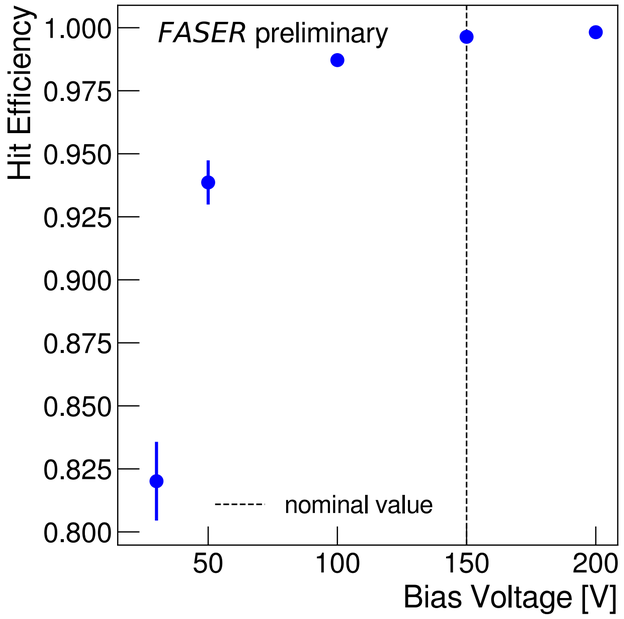
First data from 13.6 TeV proton collisions

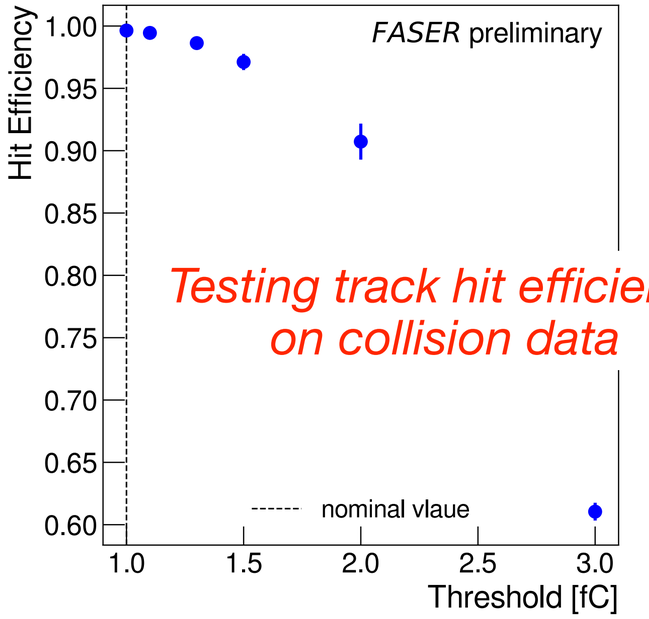
Early physics runs dedicated to tracker performance

- Special runs during early collisions used for tracker fine time tuning + hit efficiency scans.



Optimising tracker fine time (aim for center)





Testing track hit efficiency on collision data

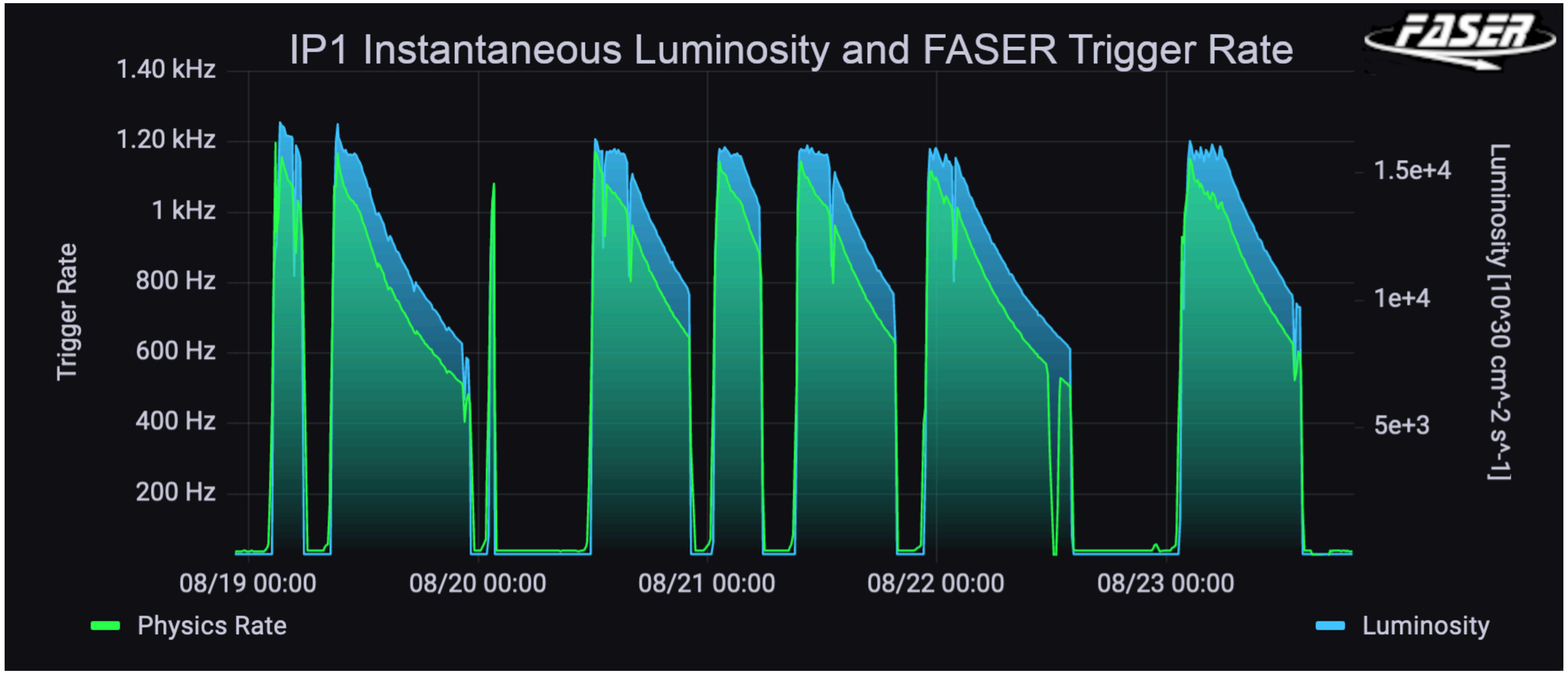
Tracker SCT modules fine time tuned with 390 ps precision. Fine Timing of all stations updated in August.

Hit efficiency dependent on hit threshold and bias voltage: Expected rise to ~100%, where our nominal values set.

First data from 13.6 TeV proton collisions

Reaching top FASER physics rates

Almost $20\ fb^{-1}$ integrated luminosity collected so far



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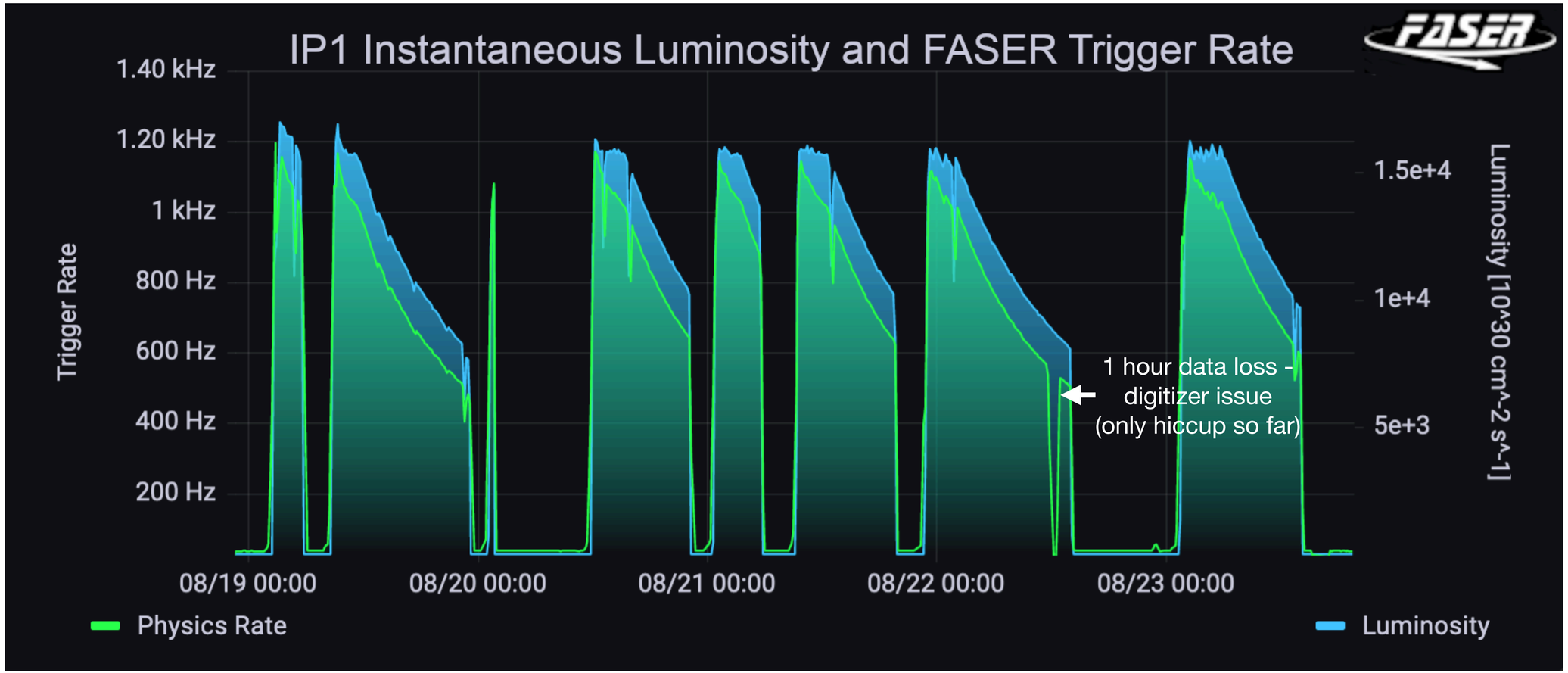

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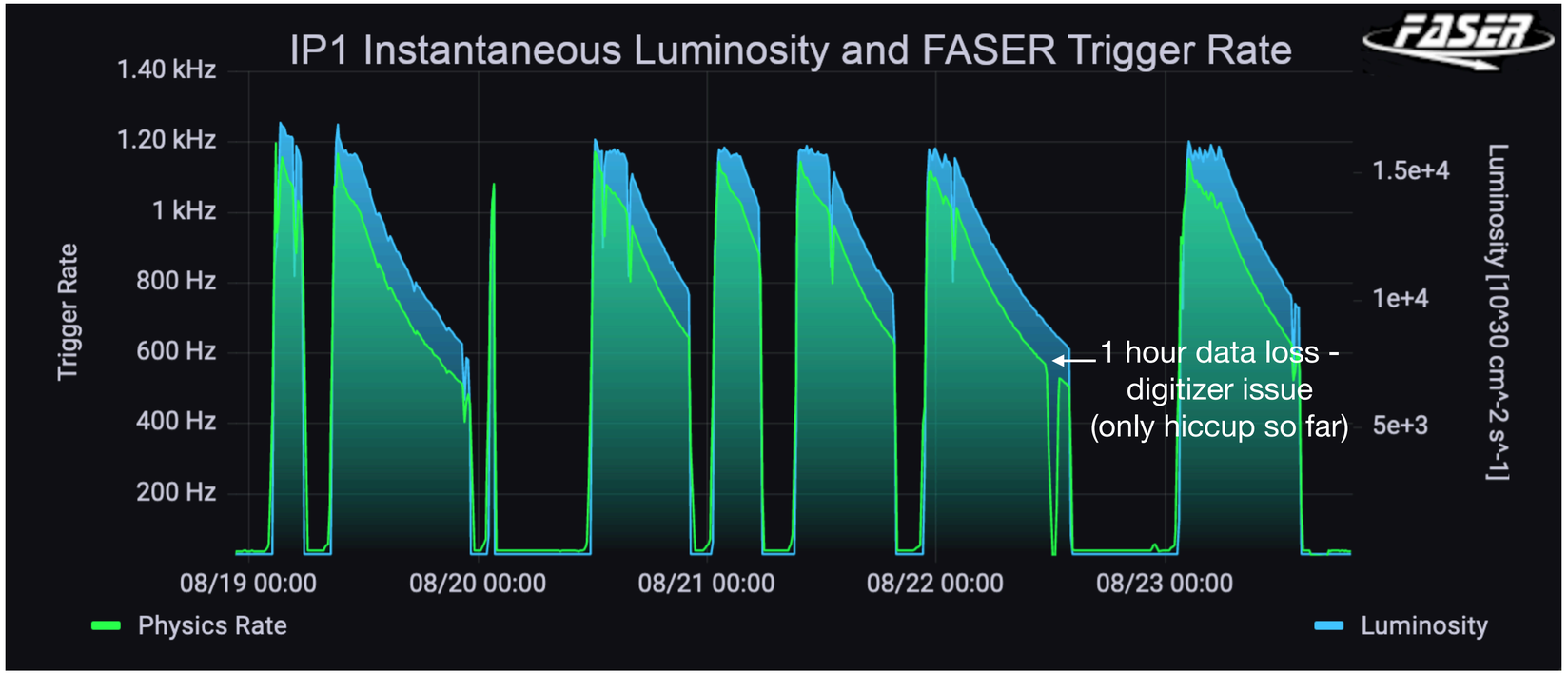
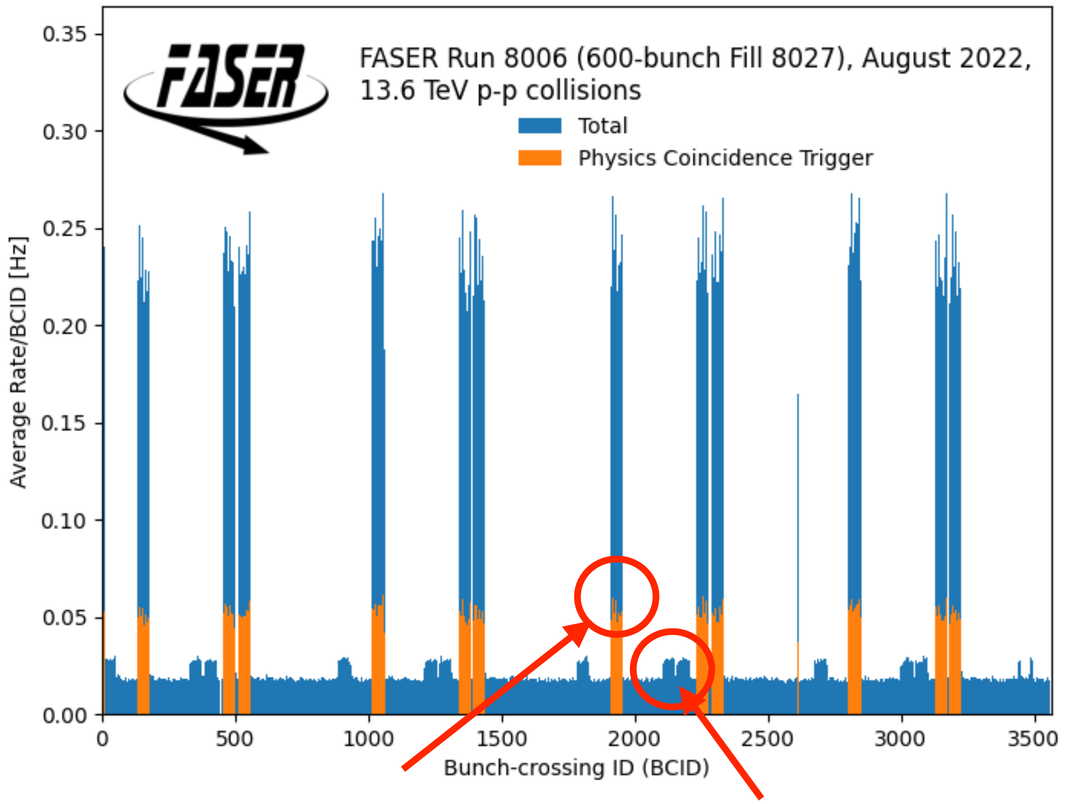


- With some unexpected observations:
  - 1.2 kHz max physics rate: *Higher* than predicted (expected 500 - 1 kHz).
  - Trigger rate trend correlation with IP1 instantaneous luminosity. However, faster drop in trigger rate than luminosity burn off at start of fills.

First data from 13.6 TeV proton collisions

Understanding trigger rates

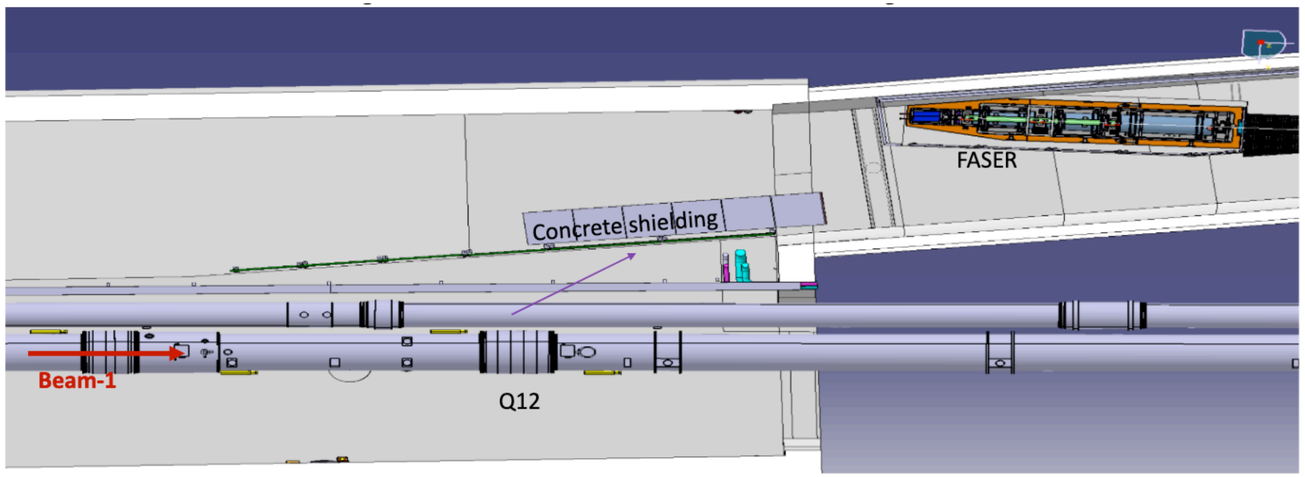
Source of rate can be established by looking at proton bunch-crossing dependence.



Collision (filled bunch) rate

Beam 1 background

- ~80% rate correlated with filled bunches (energetic muons)
  - 1/5 leading to coincidence trigger (straight-through muons)
- ~3% beam 1 background
  (beam interaction with Q12 leads to background particles, not completely stopped by concrete shielding)
- ~1% cosmics/noise-induced rate



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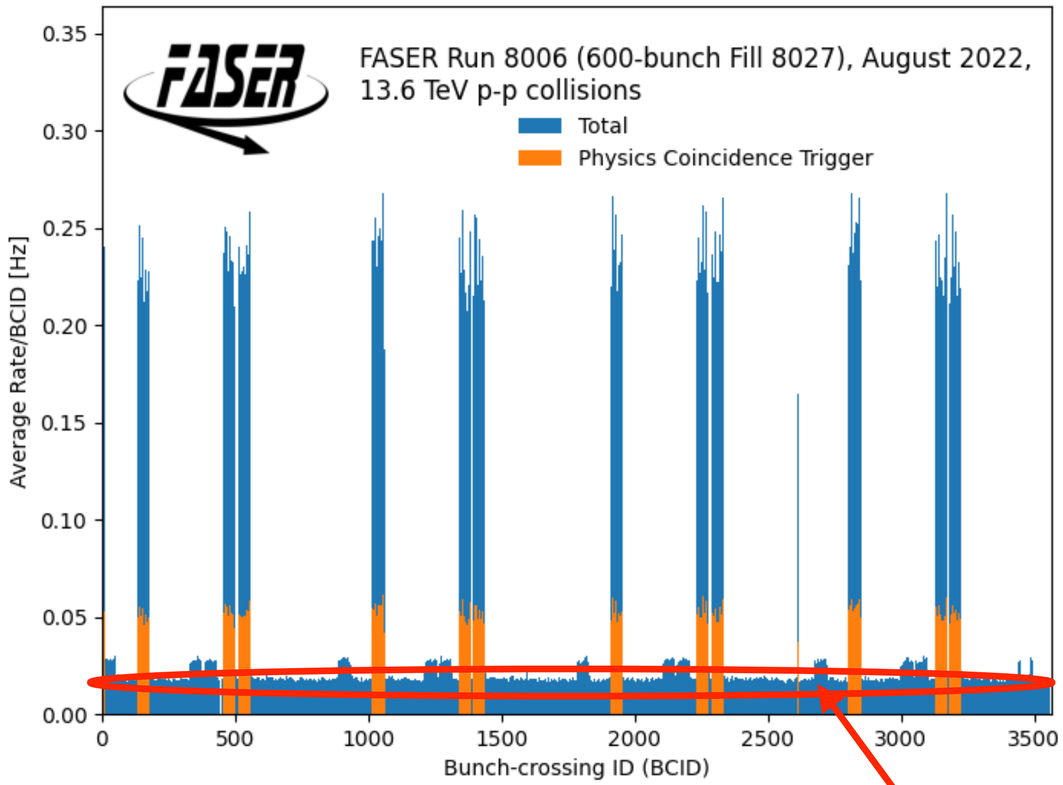
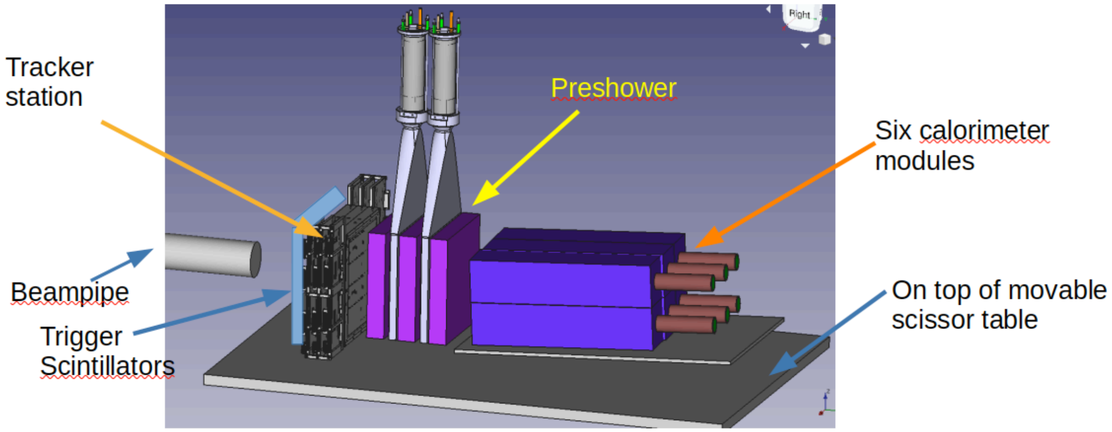


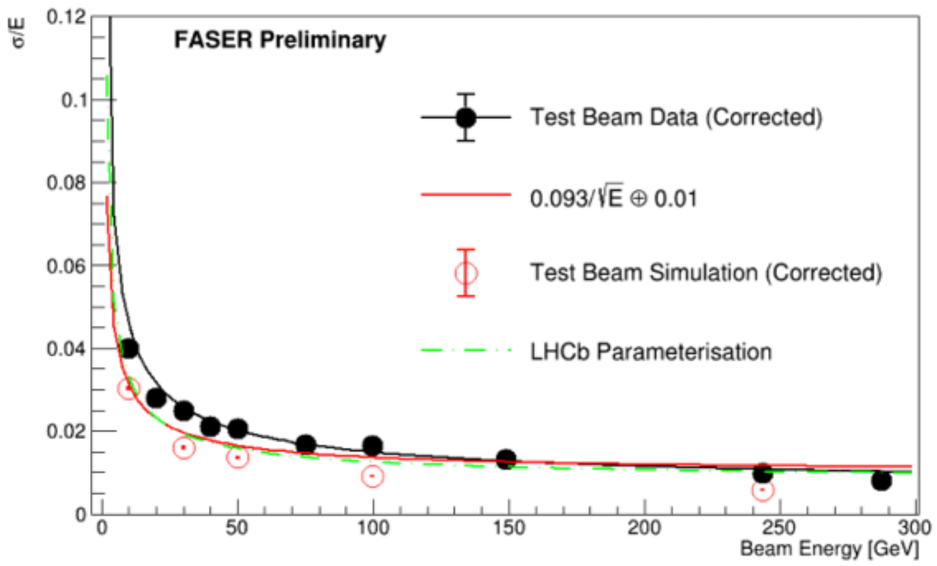
"ambient" rate with burn off during fill

- ~80% rate correlated with filled bunches (energetic muons)
  - 1/5 leading to coincidence trigger (straight-through muons)
- ~3% beam 1 background
  (beam interaction with Q12 leads to background particles, not completely stopped by concrete shielding)
- ~1% cosmics/noise-induced rate
- + ~20% "ambient" rate with no bunch correlation.
  - Suspect related to beam losses (greater at beginning of fill) causing slow moving particle background (neutrons).
- Increased rates not problem for FASER Physics.
  - Trigger system handles extra rate, < 2% deadtime.
  - Beam background can be effectively removed offline with timing cuts.

FASER Data Analysis

Towards calibrating data for physics analyses

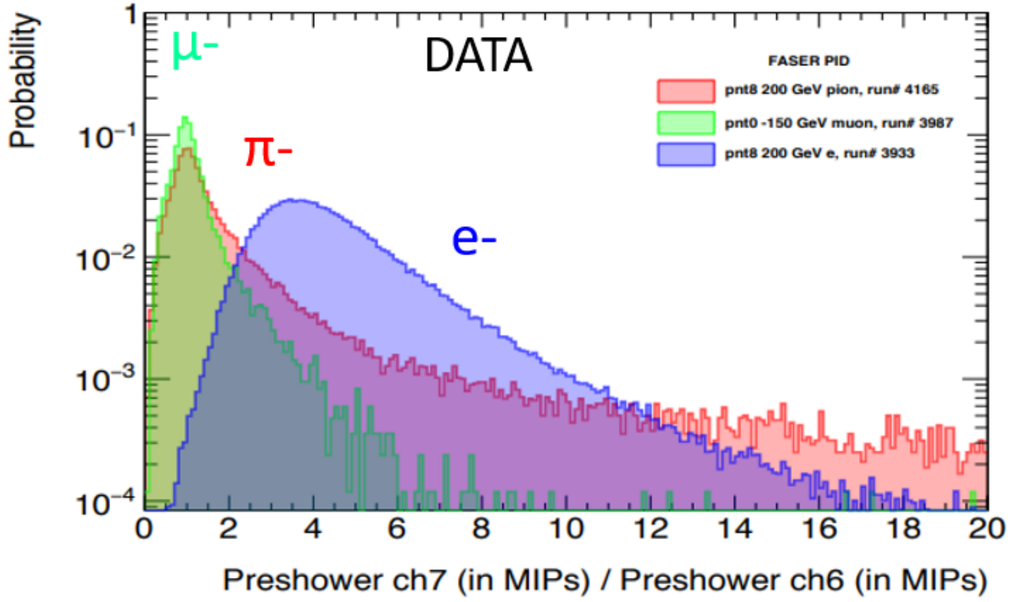




Ongoing studies to understand and improve simulation vs data resolution difference.

Summer 2021 Test Beam Data Analysis

- Dedicated Test Beam at CERN SPS last year to obtain calibration data for calorimeter modules.
- Test Beam data also used to study tracker alignment, data vs simulation, particle identification capabilities.



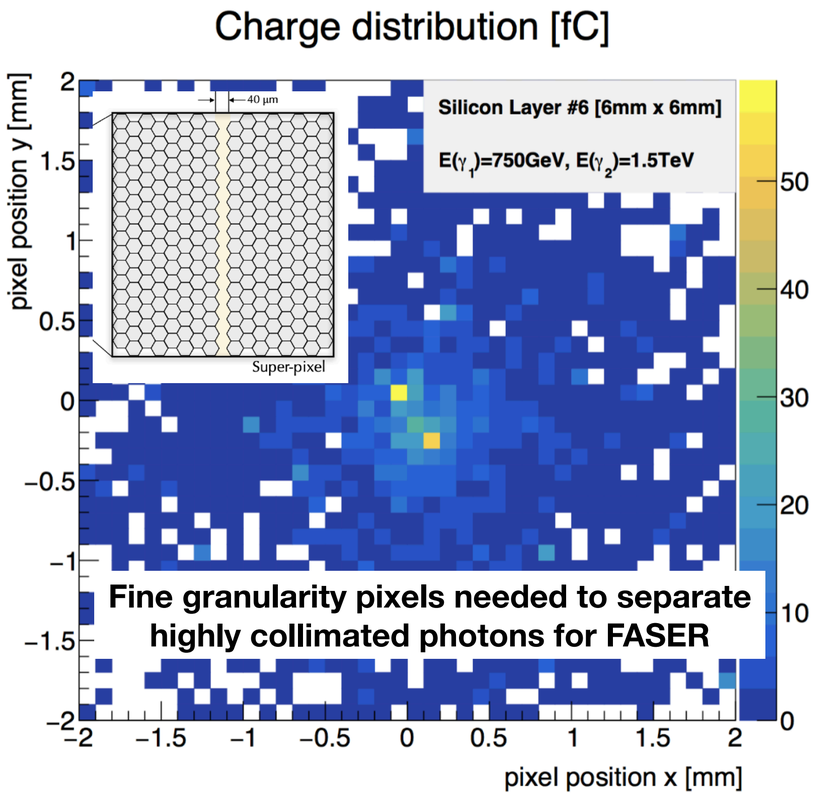
Particle identification in data using Preshower scintillators + tungsten

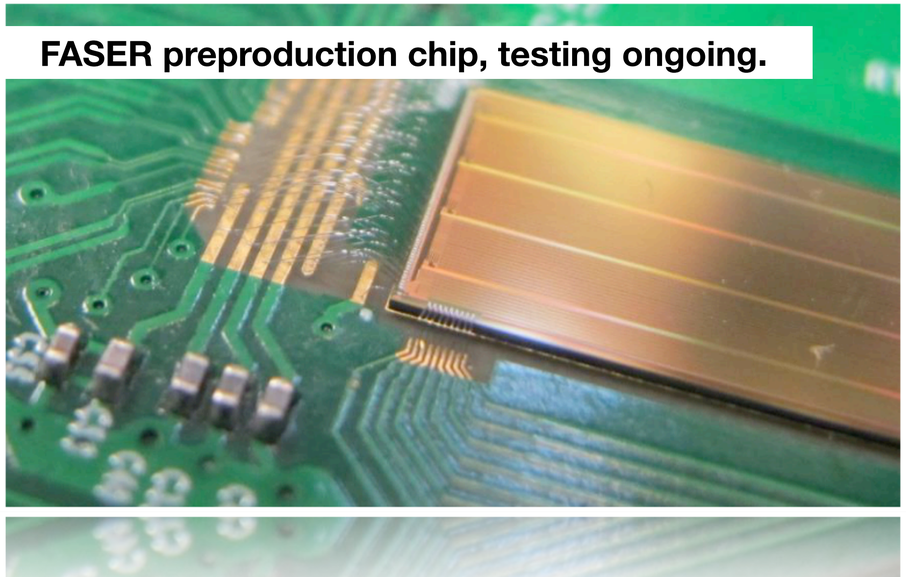
FASER Preshower Upgrade

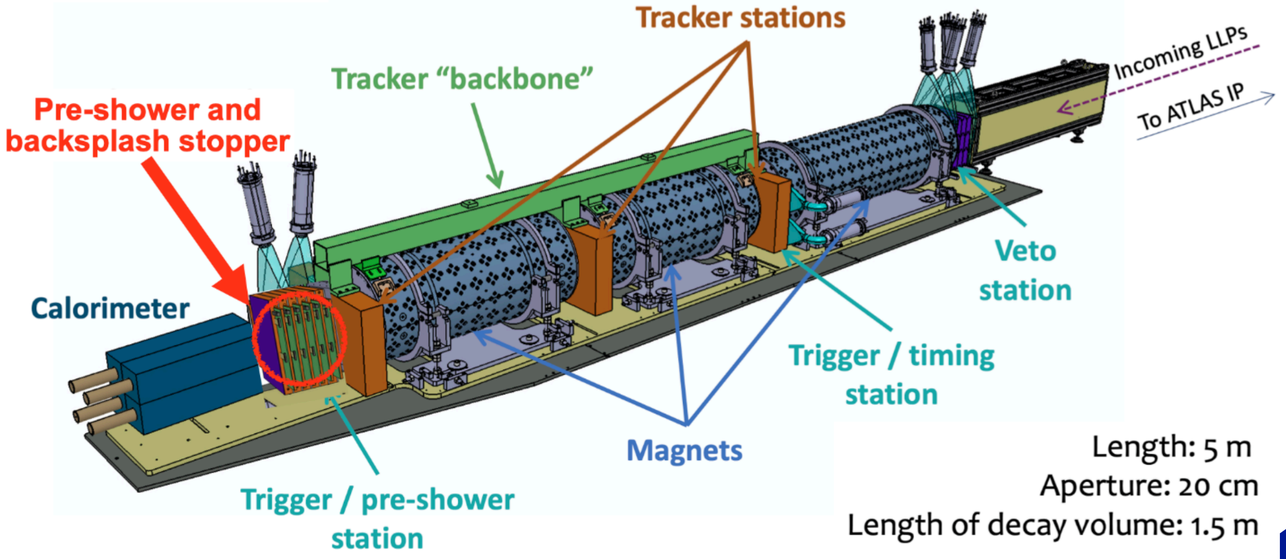
For ALPS->γγ

CERN-LHCC-2022-006

- FASER not capable of separating highly boosted ALP → $\gamma\gamma$ decay with current calorimeter: For E ~ 1 TeV, < 1 mm photon separations.
- FASER Run 3 upgrade to replace current preshower with high precision monolithic pixel sensors (pixel pitch 100 μm) + tungsten absorber plates (up to 6 radiation lengths).
  - High dynamic range, readout of large number of pixels.
- Lab testing following Test Beam for preproduction ASICs ongoing.







Summary

FASER is a new Run 3 experiment ~500 m along beamline of LHC ATLAS interaction point, in search for long lived particles such as dark photons & axions + studying high energy neutrinos.

Almost 20 fb^{-1} integrated lumi of data collected so far, with sensitivity to dark photons in unconstrained regions of parameter space.

Interesting things learned about our environment in the tunnel since start of data taking (unexpected background rates, downstream collimator effects).

Looking ahead ….

Lots of development for calibration and data vs sim studies ongoing for physics analysis.

Getting ready for FASER preshower monolithic pixel upgrade for enhanced sensitivity to New Physics -> γγ .

+ FASER 2 planning at HL-LHC in a Forward Physics Facility: See Felix's talk directly after this.

Thanks for listening!

The FASER Collaboration

https://faser.web.cern.ch

We owe many thanks to: HEISING-SIMONS FOUNDATION, SIMONS FOUNDATION, CERN for financial and technical support.

Back Up

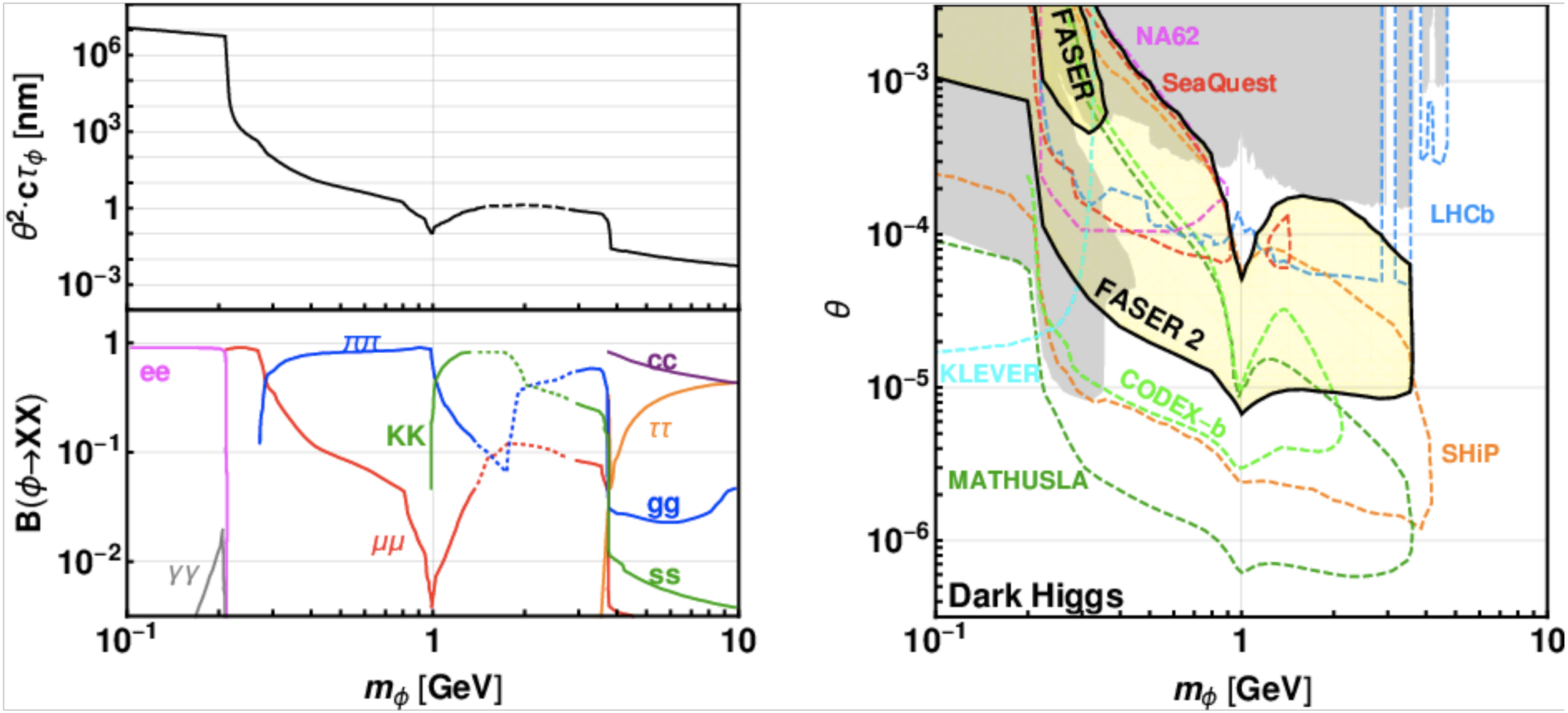
Assumptions in Sensitivity

Assumptions by other experiments in sensitivity plots:

NA62 assumes 10^{18} protons on target (POT) while running in a beam dump mode that is being considered for LHC Run 3; SeaQuest assumes 1.44×10^{18} POT, which could be obtained in two years of parasitic data taking and requires additionally the installation of a calorimeter; the proposed beam dump experiment SHiP assumes $\sim 2 \times 10^{20}$ POT collected in 5 years of operation; the proposed electron fixed-target experiment LDMX during Phase II with a beam energy of 8 GeV and 10^{16} electrons on target (EOT); Belle-II and LHCb assume the full expected integrated luminosity of 50 ab^{-1} and 15 fb^{-1}, respectively; HPS assumes 4 weeks of data at JLab at each of several different beam energies; NA64 corresponds to 5×10^{12} EOT with 100 GeV energy; and AWAKE is assumed to be working as a fixed-target experiment with a 10-m-long decay volume and 10^{16} EOT accelerated in a 50 – 100 m long plasma cell to the energy O(50 GeV).

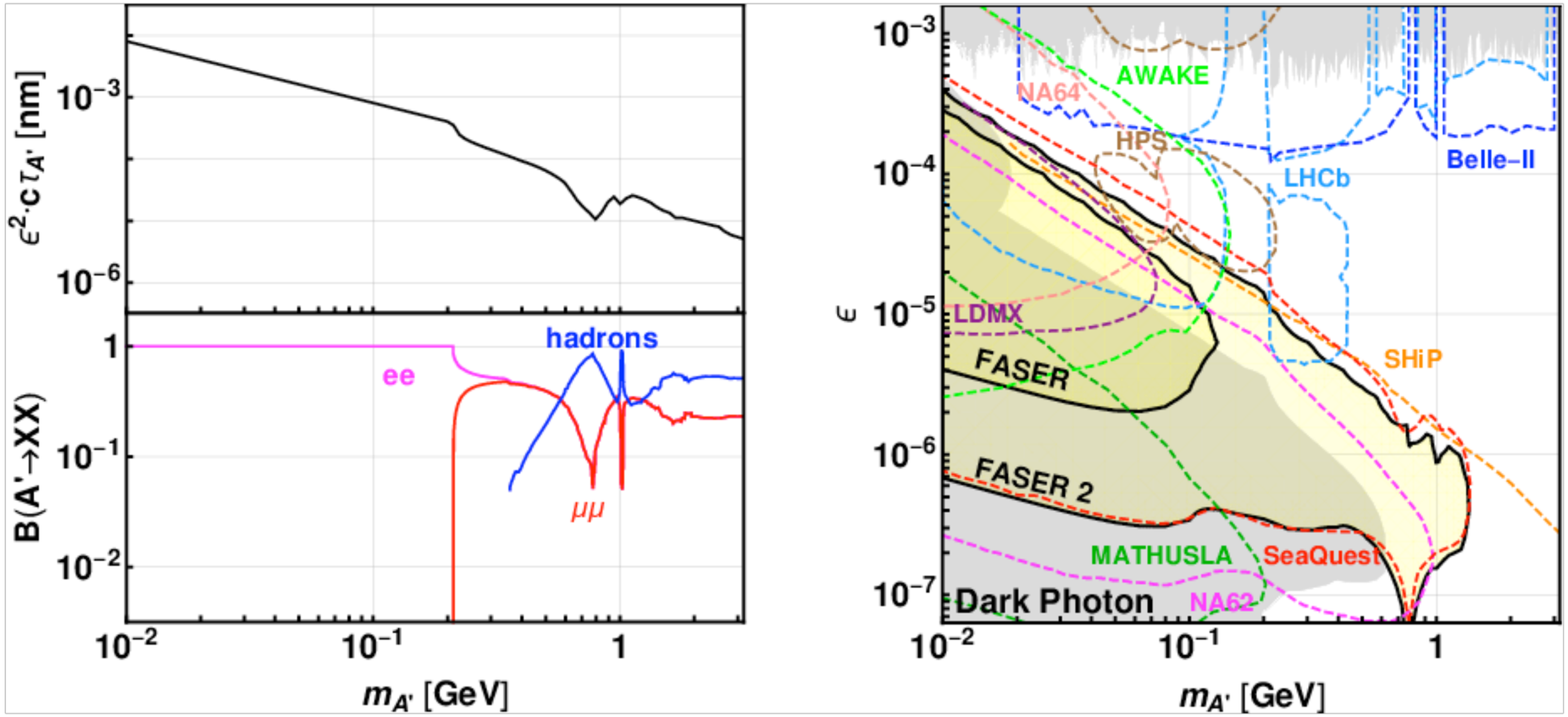
Dark Higgs sensitivity

Without trilinear coupling

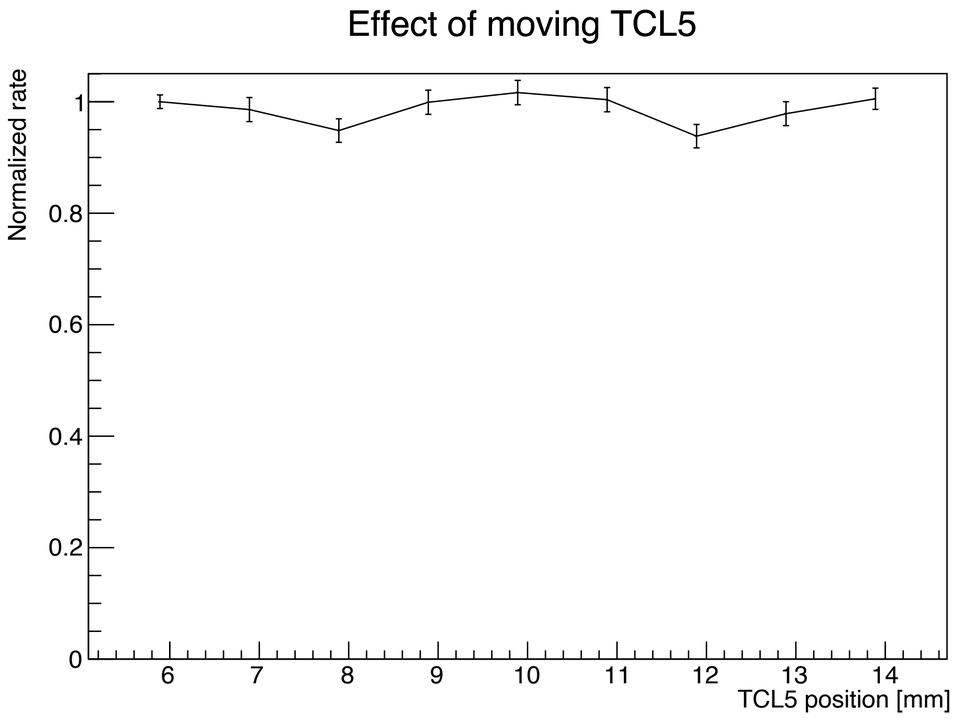


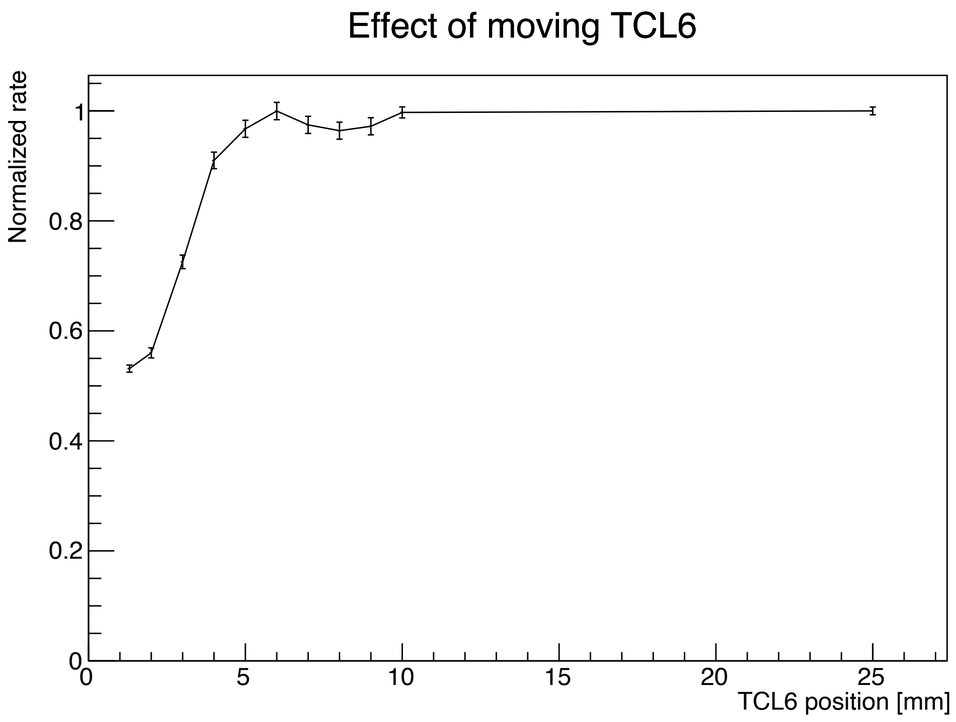
Dark Photon to visible decays

Sensitivity



FASER Rate vs Collimator Position





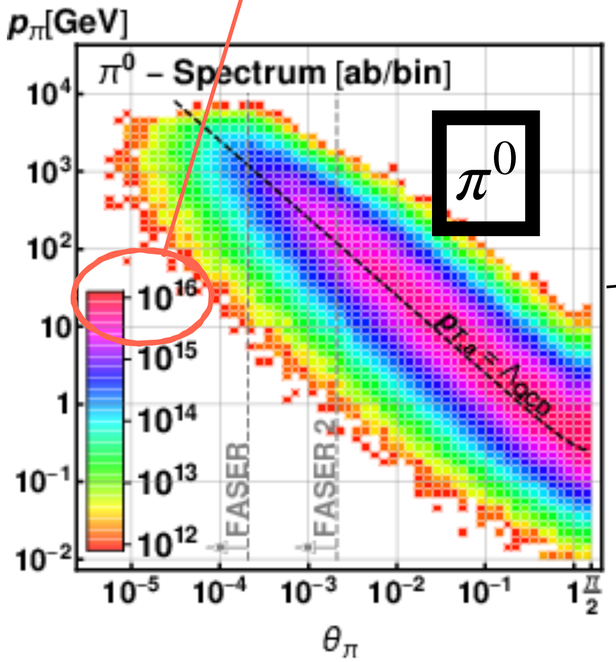
FASER Overview

Physics

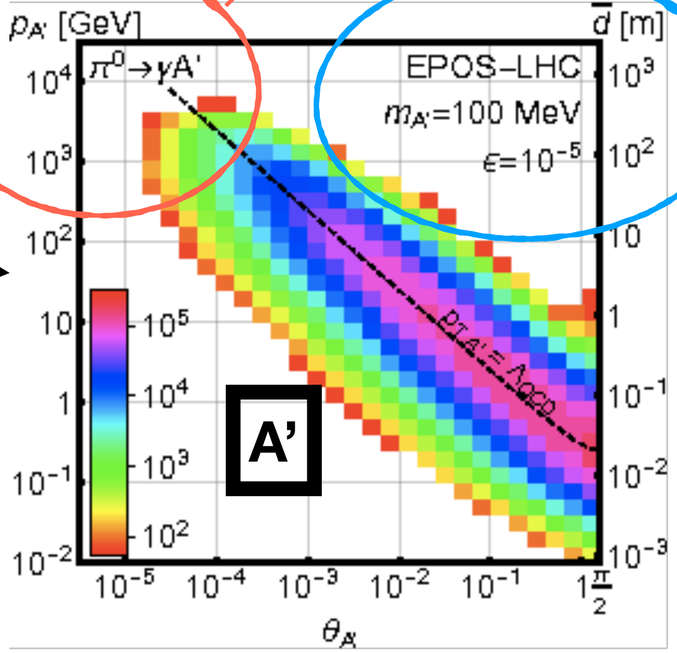
Large luminosity of highly energetic neutral pions:
Source of new boosted physics down beam pipe

10^{16} inelastic events in 150 ifb

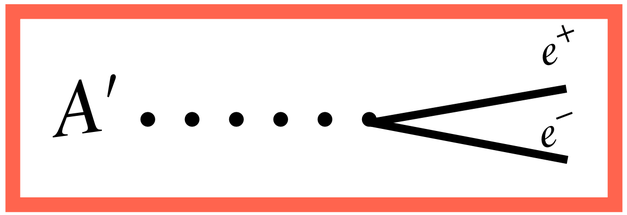
Highly energetic & boosted (TeV energies) if produced close to beam line.



π^0 ..... A' γ



Small SM couplings + boost
-> Long-lived, can decay far from collision to highly collimated SM particle pair.



Preshower Upgrade

Simulated 2 γ reconstruction efficiency

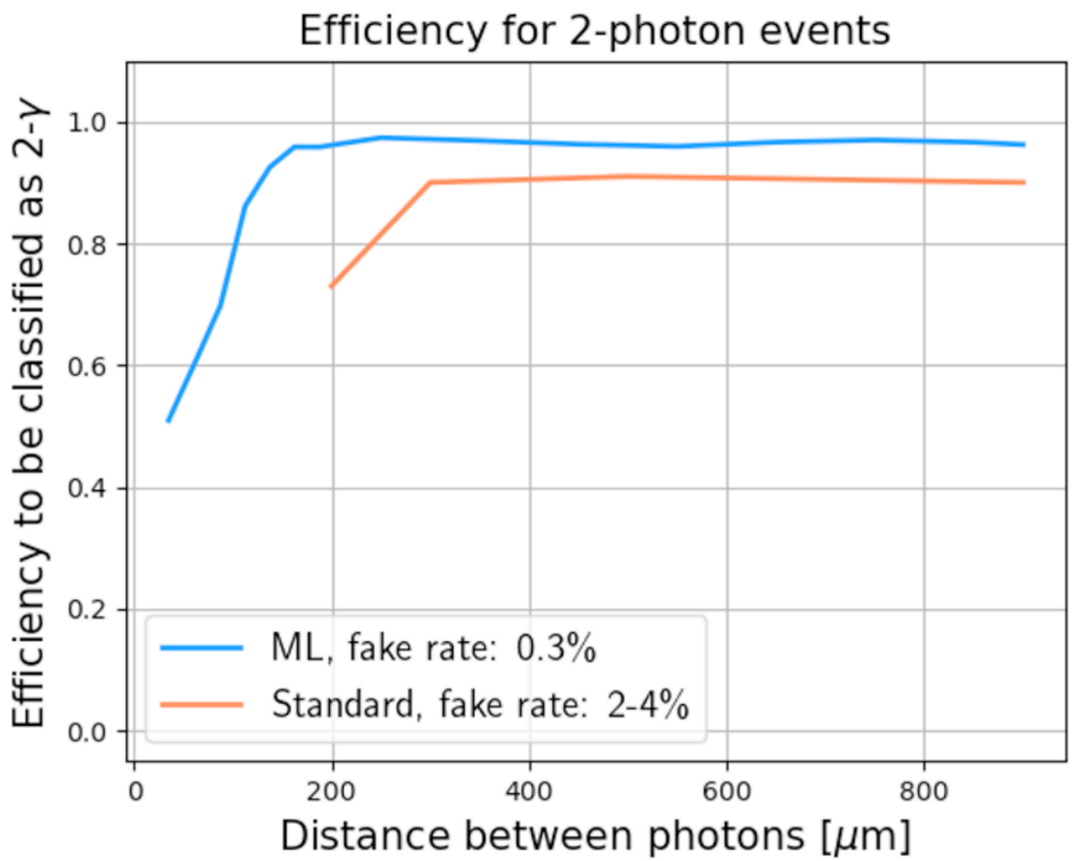


Figure 4: Di-photon event tagging efficiency expected for the upgraded preshower. The orange line shows the results obtained with the purposely-developed conventional algorithm. The blue line shows the results obtained with a Machine-Learning-based approach. Photons of 1 TeV energy are considered in this study.

Preshower Upgrade

Sensitivity to ALPS

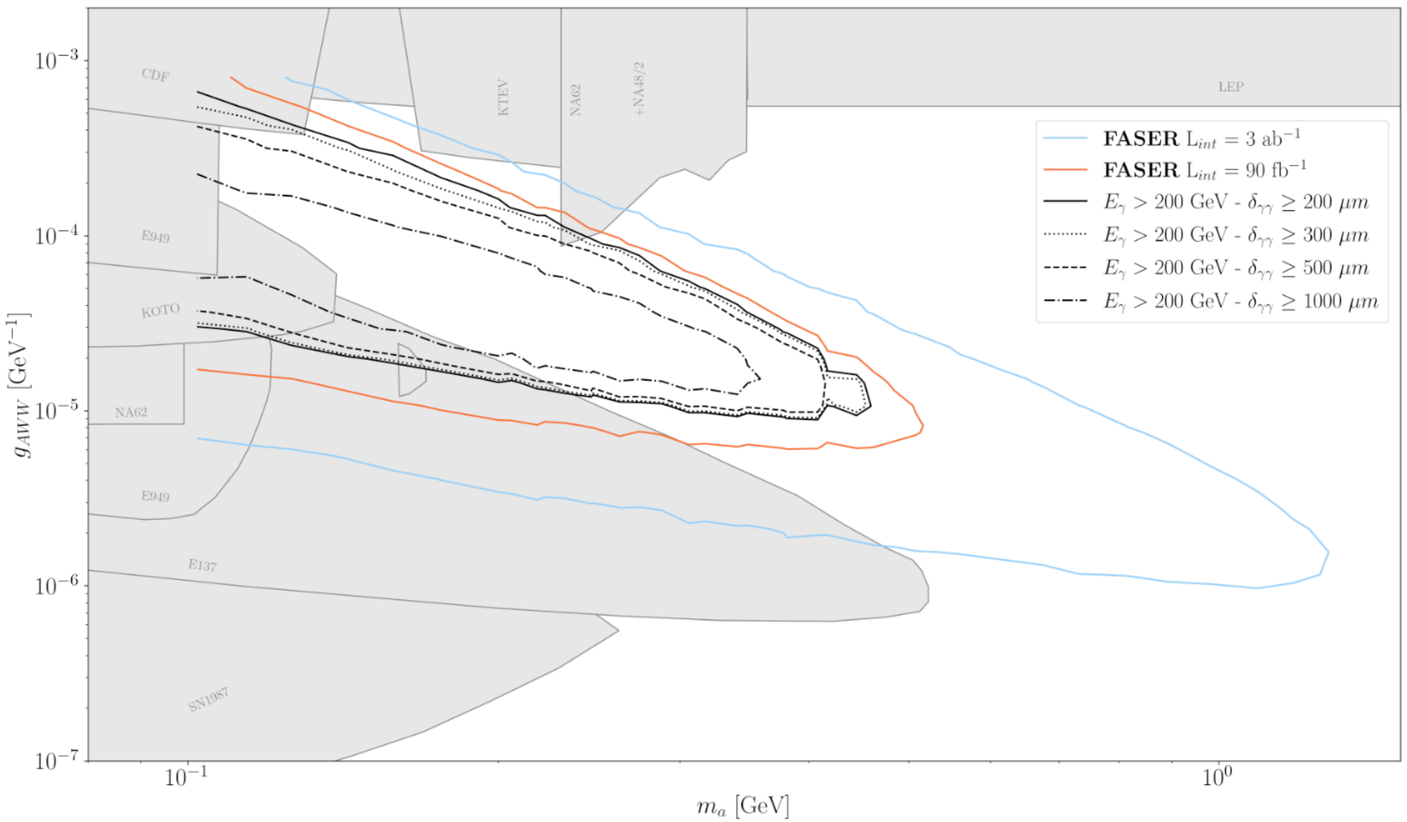
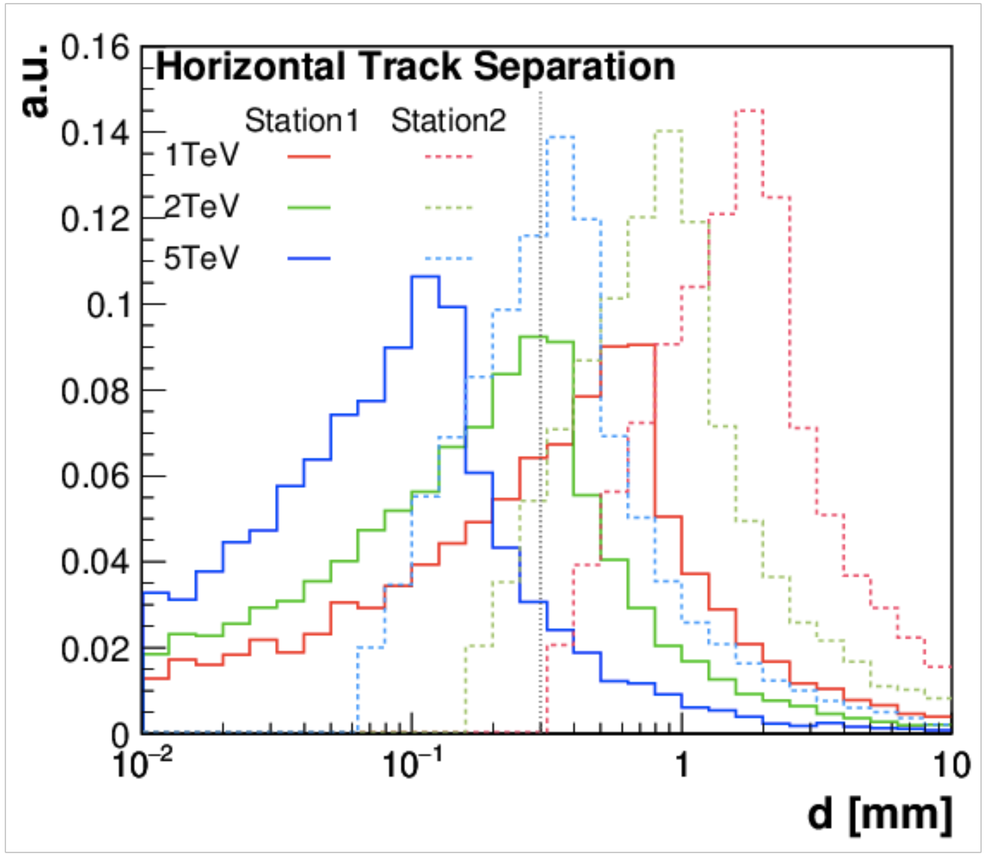
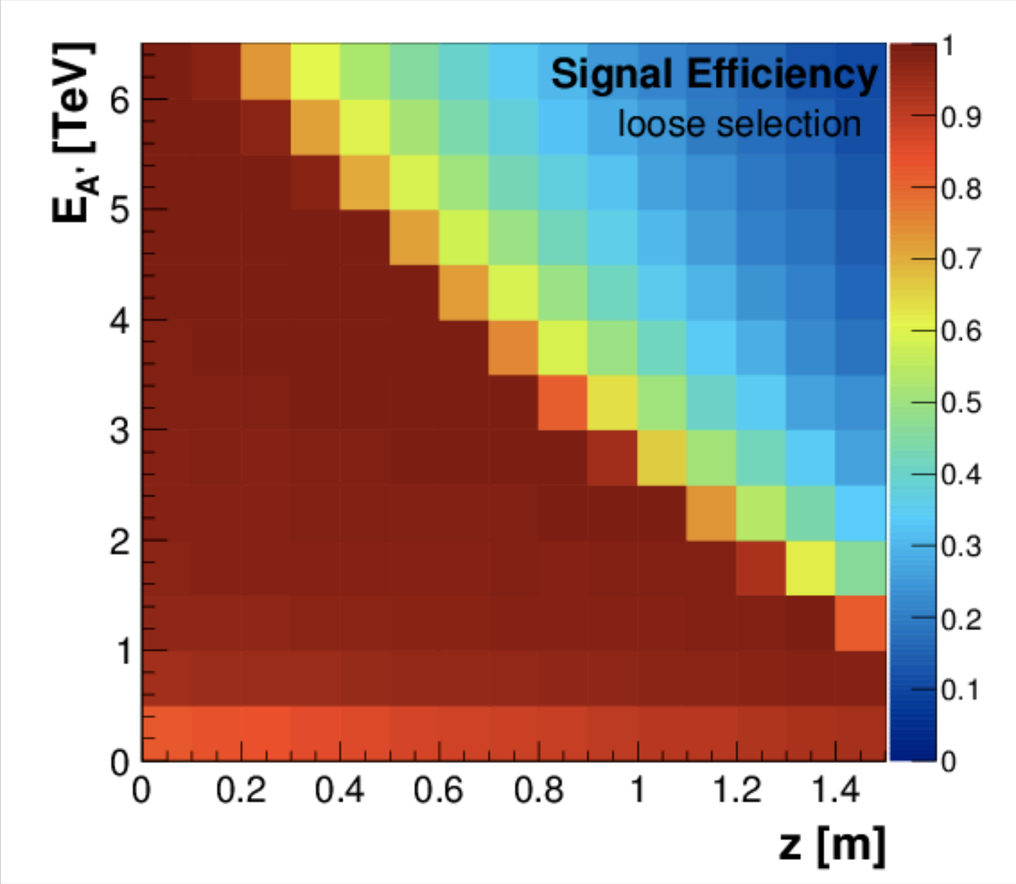


Figure 5: Sensitivity reach of the FASER W-Si preshower in the ALP parameter space. The blue and red lines show the reach for an ideal detector with 100% photon-pair reconstruction efficiency for the Run-3 (90 fb^{-1}) and HL-LHC (3 ab^{-1}) expected integrated luminosities for 14 TeV collision energy. The black lines show the sensitivity reach for 90 fb^{-1} of data including simulated efficiencies for photon-pairs with $E_\gamma > 200$ GeV and various values of $\delta_{\gamma\gamma}$. The grey-shaded regions represents the parameter space currently excluded by experiment [10][6].

FASER Simulated Signal Efficiency

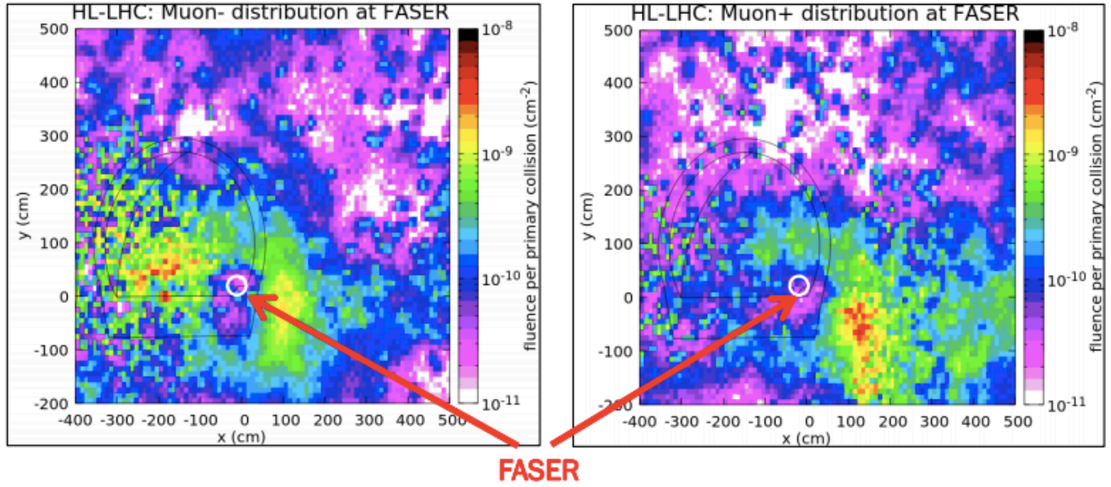
mA'=100 MeV, ε = 10^{-5}

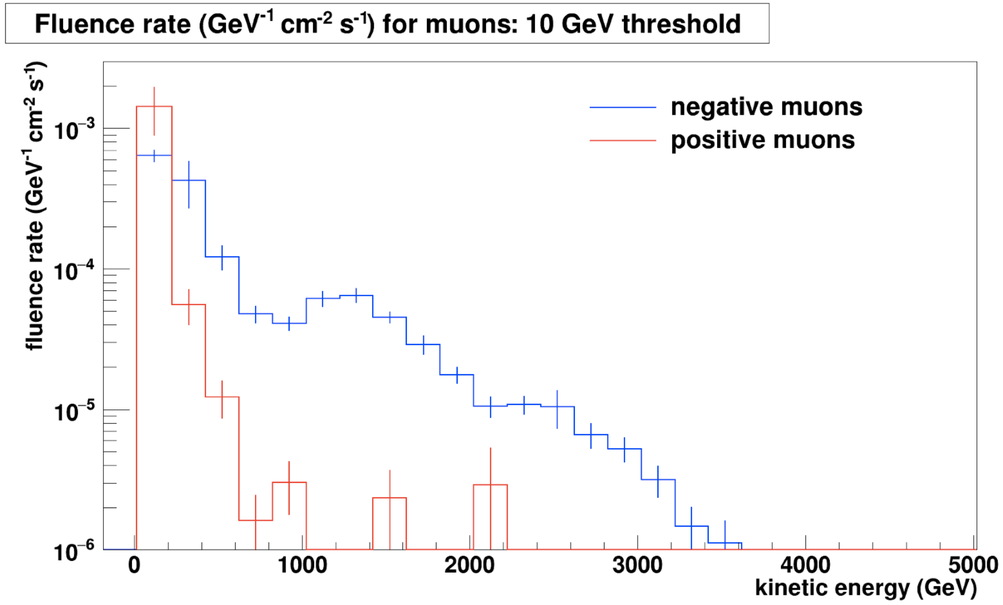




FASER Background

FLUKA simulation: Magnets very helpfully deflect muons away from beam axis.

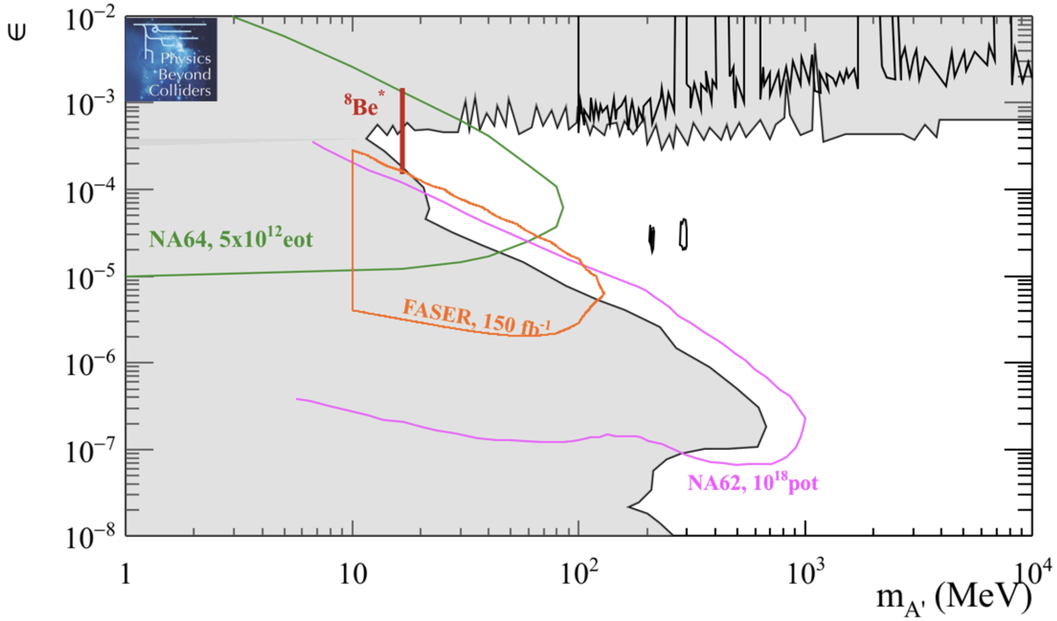


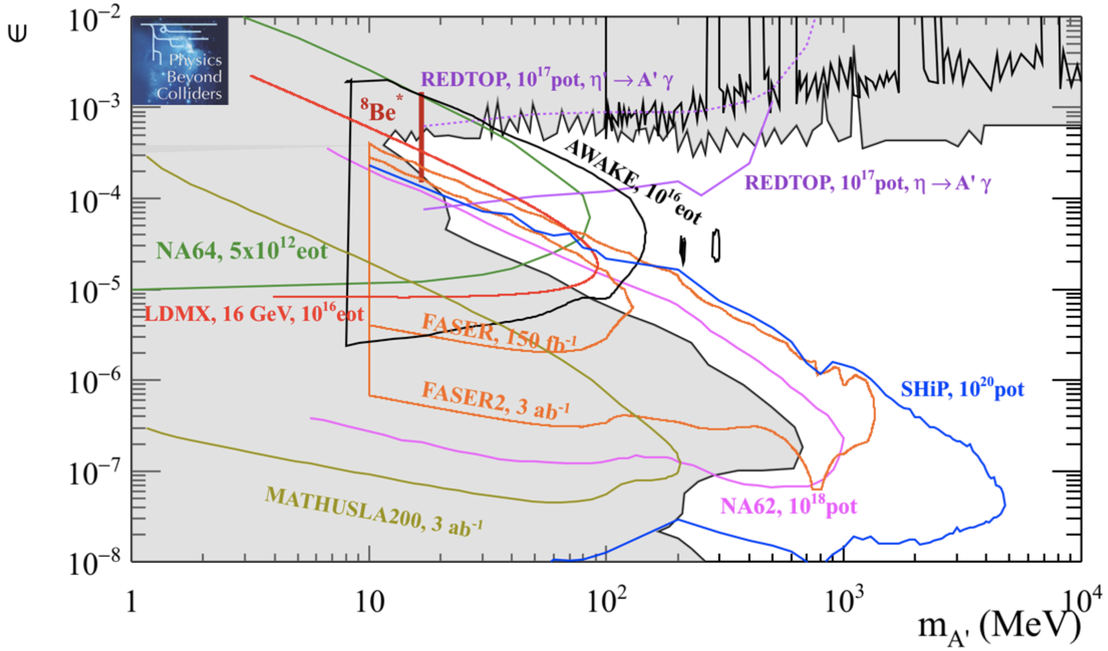


Dark photon to visible decay

Projections

- 5 year timescale





- 10-15 year timescale

Ref: [Physics Beyond Colliders Working Group Report]