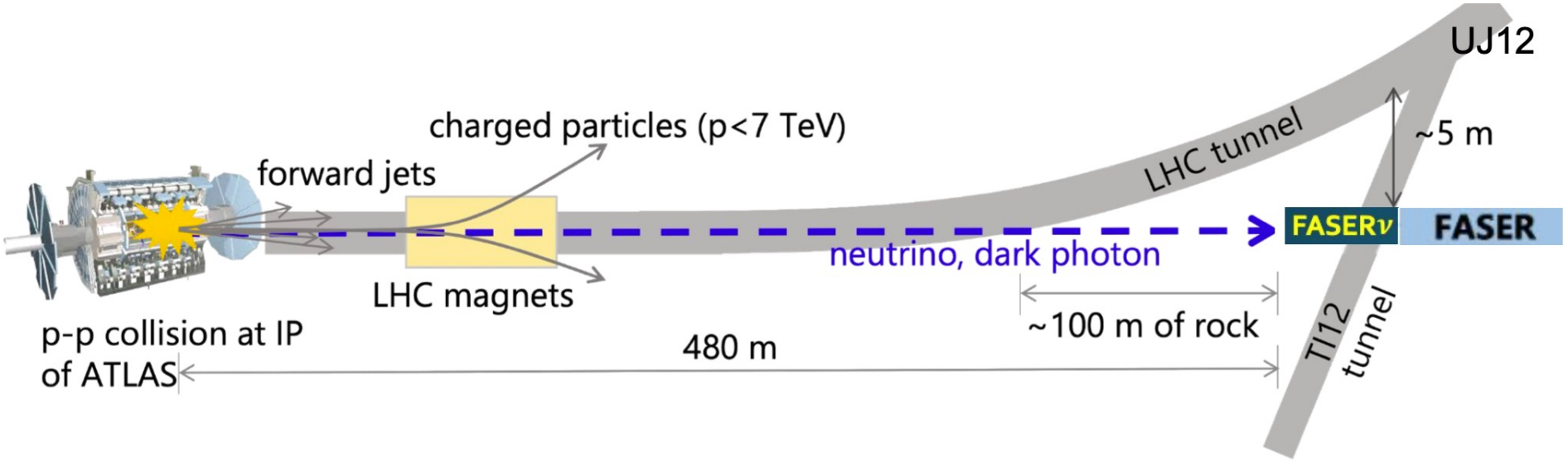
Search for Weakly Interacting Particles with the FASER Experiment

Matthias Schott on behalf of the FASER Collaboration

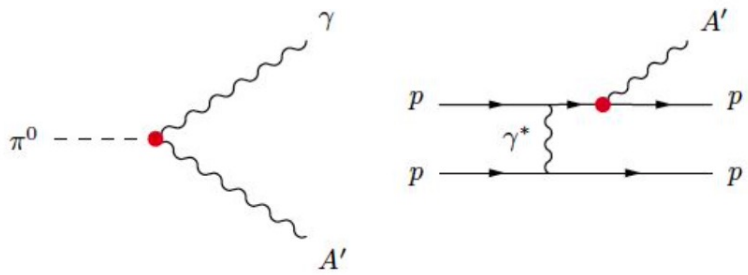
The general idea

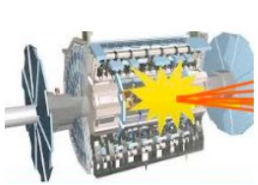
- Huge cross-sections at the LHC
  - $N_{inel} \approx 2.3 \times 10^{16}$ inelastic pp scattering events for an integrated luminosity of 300 fb^{-1}
  - Extremely weakly-coupled and light new particles may be produced in sufficient numbers in the very forward region.
- Such particles may be highly collimated
  - typically produced within $\theta \sim \Lambda_{QCD}/E$
  - implies that ~100 m down-stream, such particles have only spread out ~10 cm in the transverse plane.



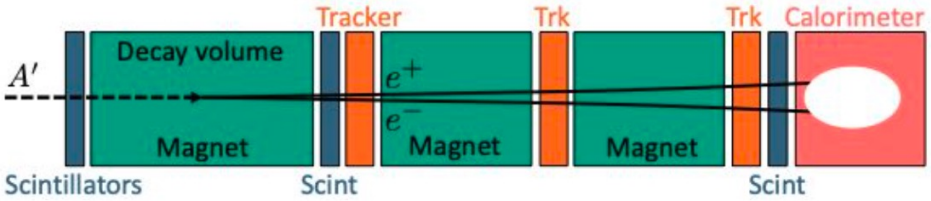
Physics Reach: Dark Photons and Dark Higgs

- Spin 1, couples weakly to SM fermions
  - Mainly from decays of light mesons, π, η, dark bremsstrahlung and hard scattering
  - Decay into electrons, muons, pions
- FASER has sensitivity to coupling strength of ~10^{-5} for dark photon.
  - Assumption: 0 background and 100% efficiency.
  - →FASER, LHCb and Belle2 are complementary and can cover most search region of $m_{A'} < 1$GeV

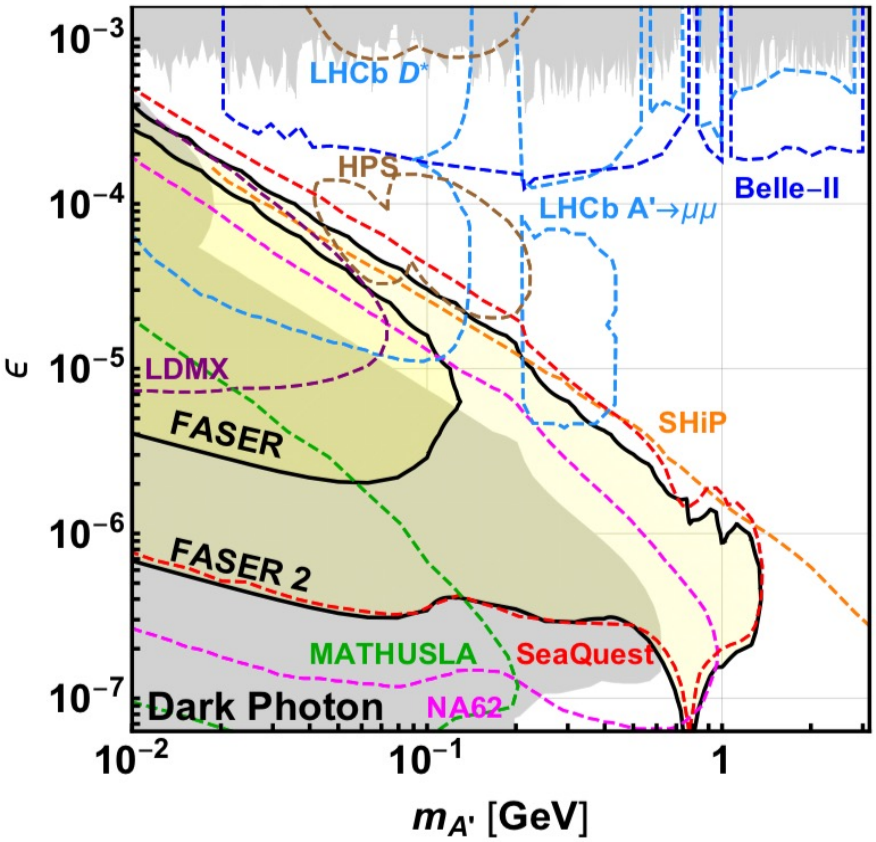


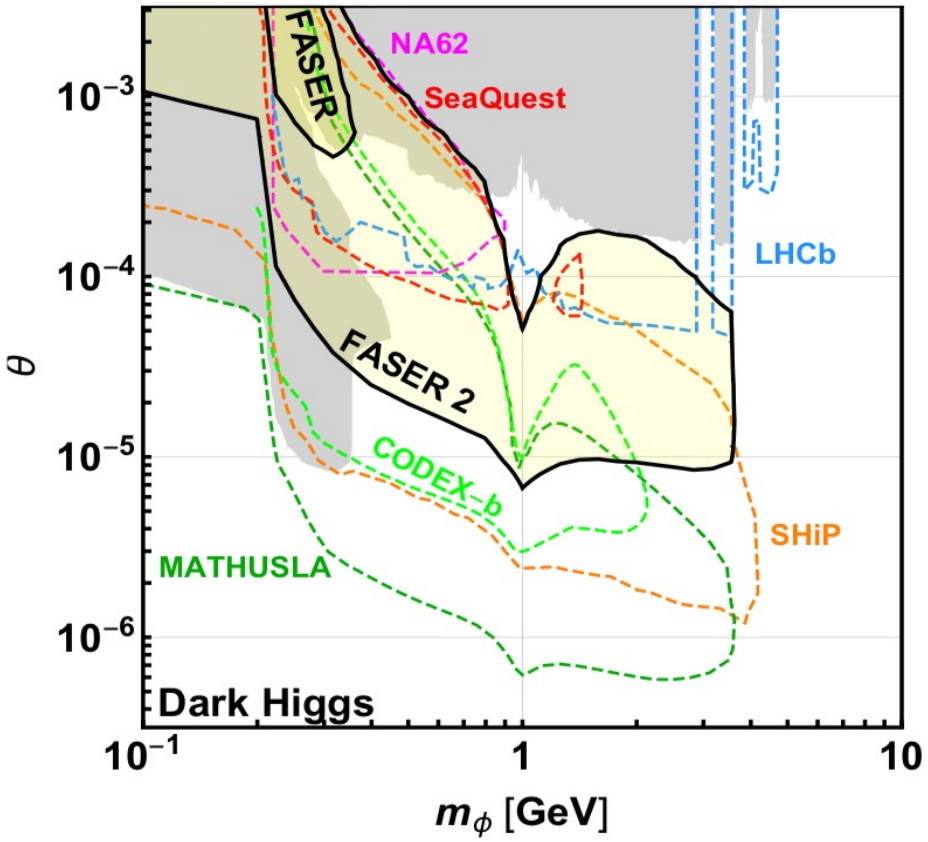


480m



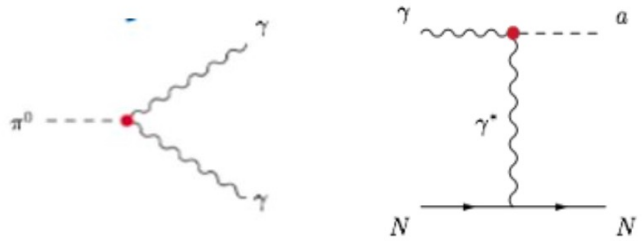
Physics Reach: Dark Photons and Dark Higgs



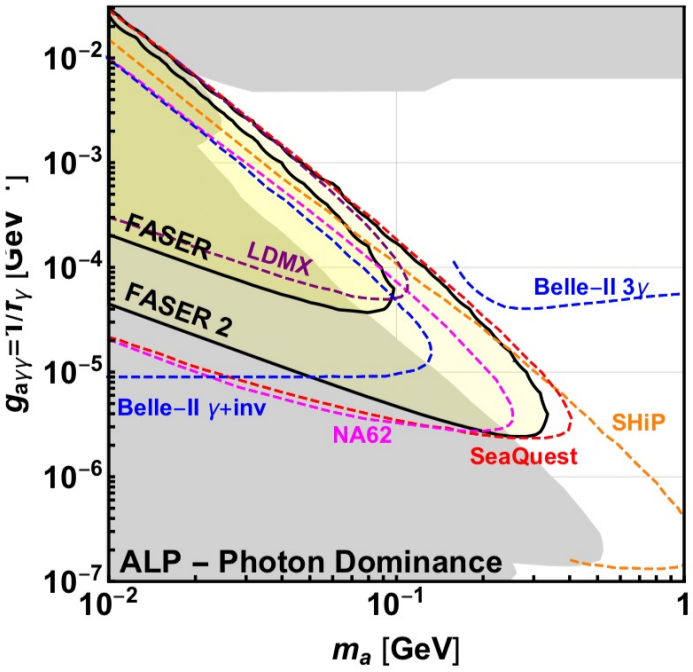


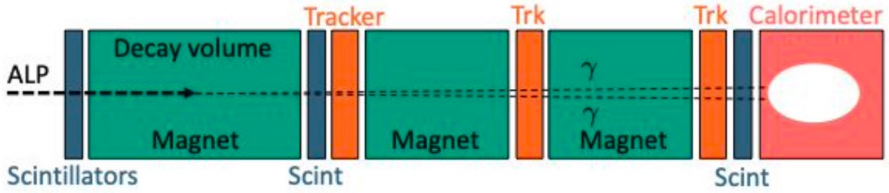
Physics Reach: Heavy Neutral Leptons and ALPs

- ALPs production via Primakoff process (γN→aN)
  - Assume only couplings to photons



- For ALP->γγ decay, magnetic field does not help separate closely spaced decay products
  - maybe pre-shower but challenging to resolve closely spaced (~1mm) high energy photons (>500 GeV)

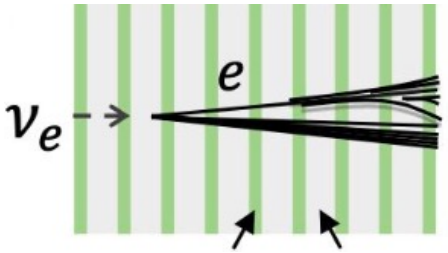


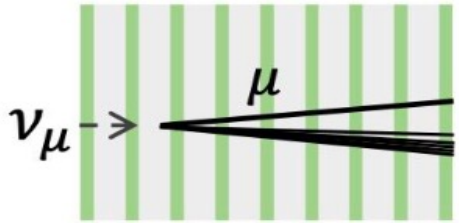


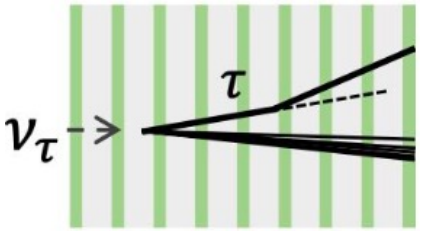
- FASER would be able to detect ALPs with $m_a \approx$MeV and $g_{a\gamma\gamma} \approx 10^{-4}$ GeV^{-1}, as those would travel up to 350m and decay then into two photons, which can be detected.

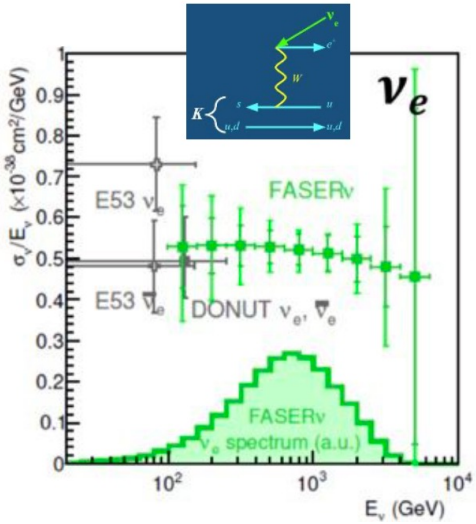
Neutrinos at FASER

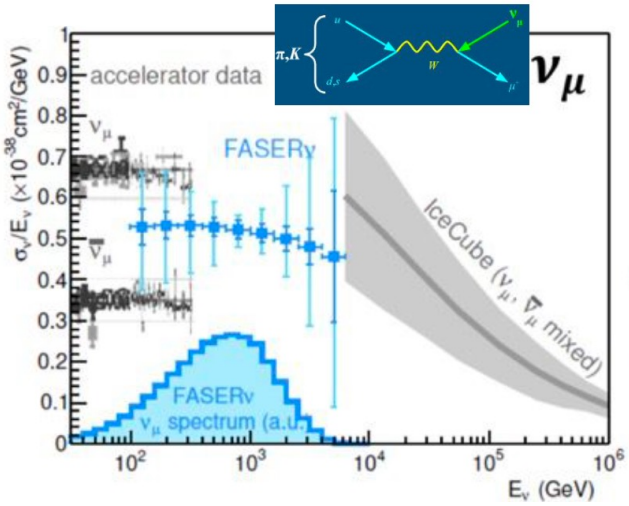
- Sensitive to new physics by measuring scattering cross sections and studying each flavor

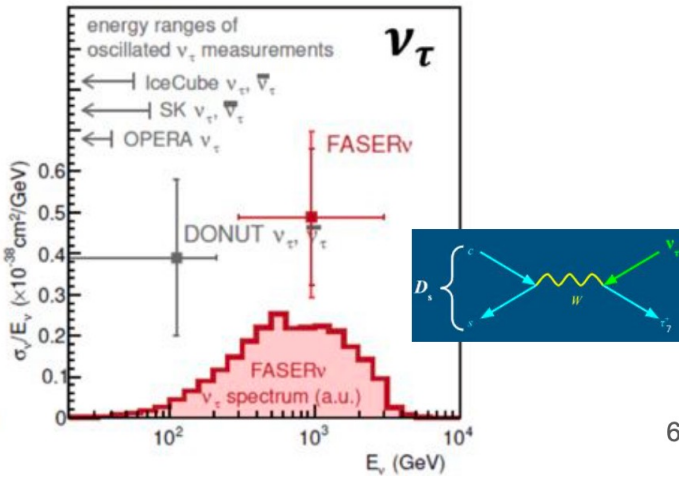




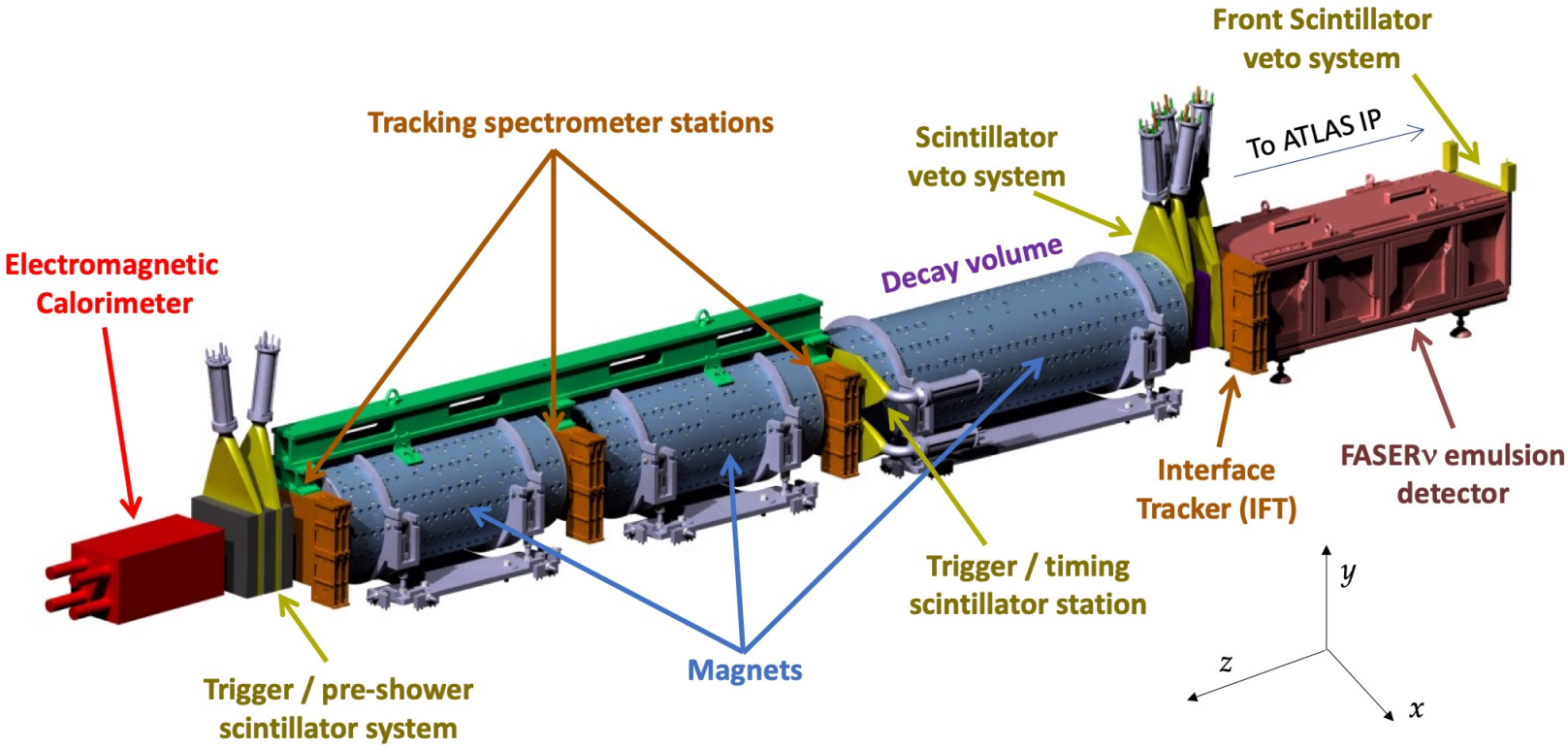


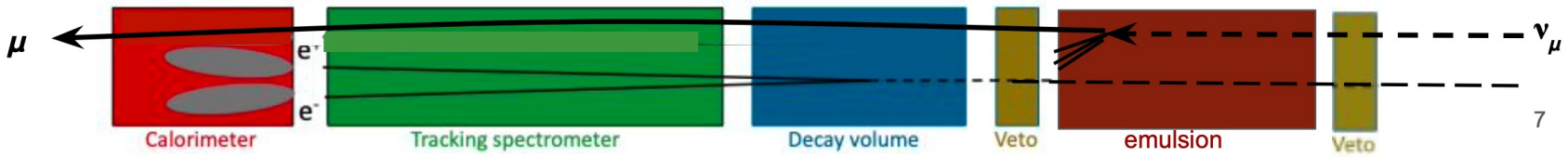






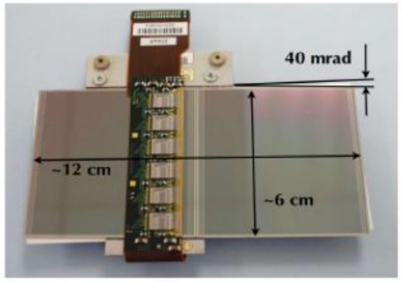
The Detector



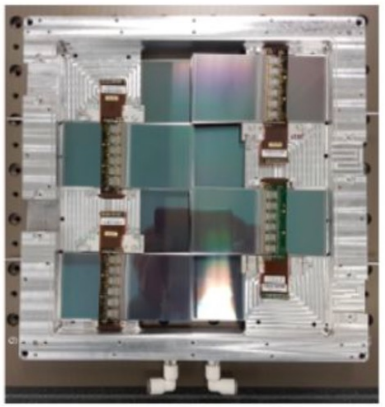


Silicon Tracker

- Based on ATLAS SCT modules:
  - 8 modules x 3 layers x 4 stations = 96 modules
  - Resolution: 17 um x 580 um
  - Good separation for two collimated tracks
  - Paper: NIMA (2022) 166825
- 4 stations commissioned and installed
  - 99.9% strips are active
  - Expected noise/gain are confirmed
  - Thermal performance as expected
  - Interlock/safety are carefully verified



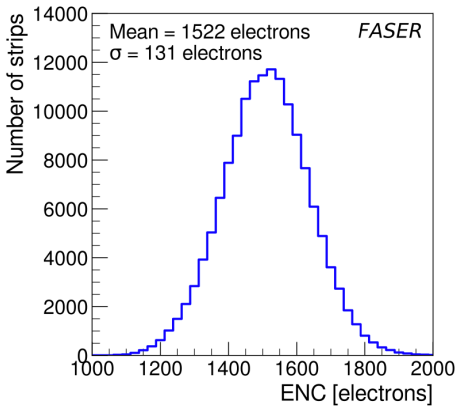
SCT module

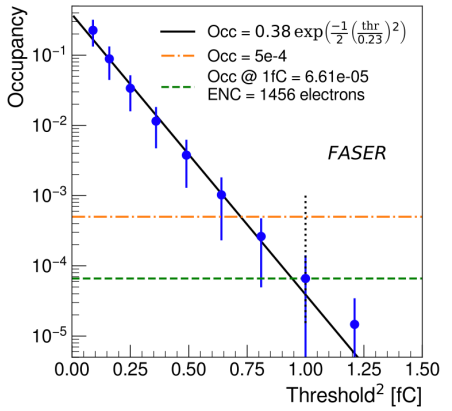


Tracking layer

80 um pitch, 768 strips/side
40 mrad stereo angle

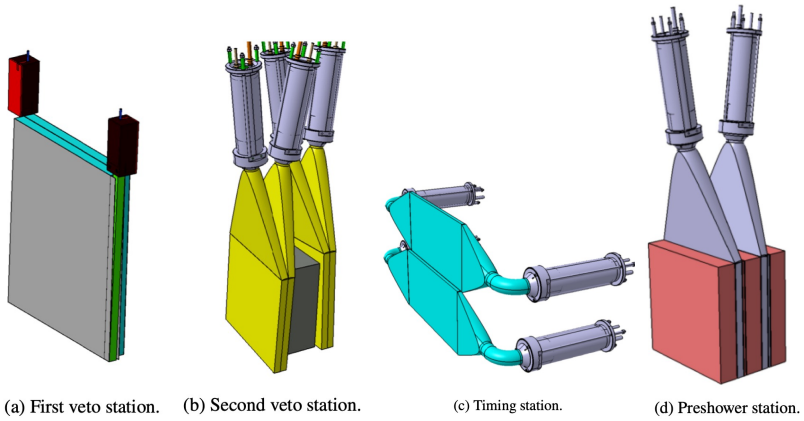
24 cm x 24 cm sensitive area





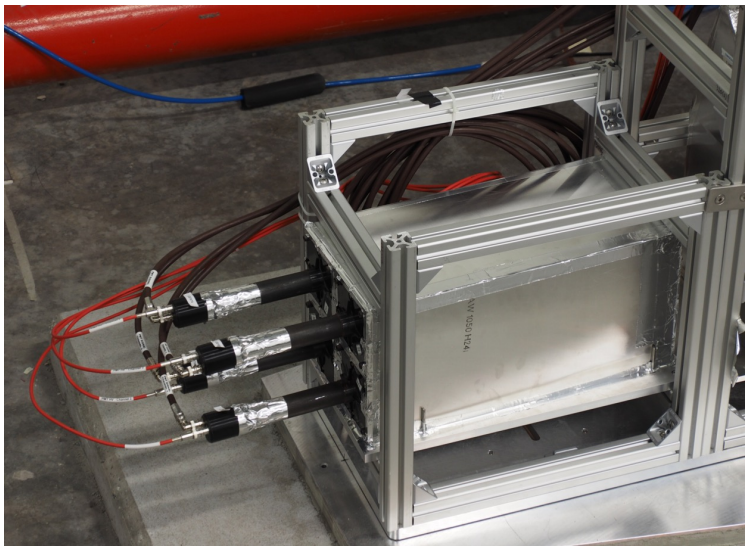
Scintillator and Calorimeter

- Four scintillator stations are commissioned and installed
  - > 99.9% efficiency, enough to trigger LLP decay inside the FASER detector
  - Confirmed by in situ measurements in 2018.



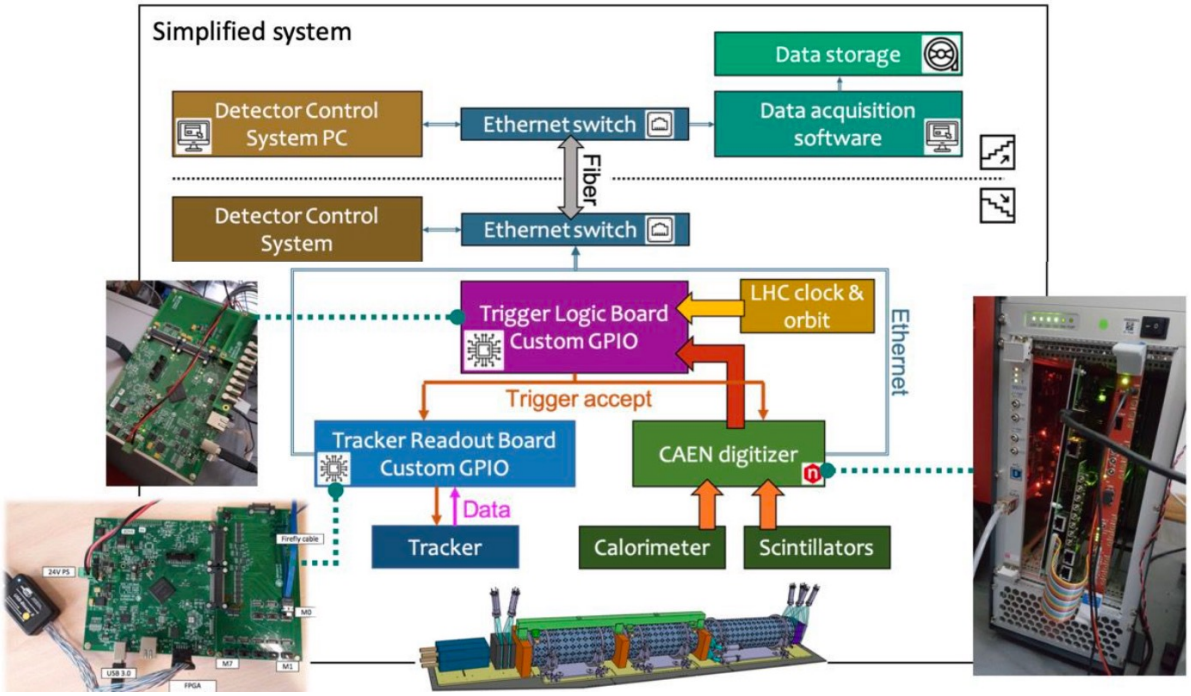
(a) First veto station. (b) Second veto station. (c) Timing station. (d) Preshower station.

- Calorimeter based on LHCb ECAL module is also installed. One module has:
  - 12 cm x 12 cm (25 $X0$)
  - 66 layers of (2mm lead and 4mm scintillator)
  - Resolution ~1% for 1 TeV electron energy deposits



Trigger and Data acquisition

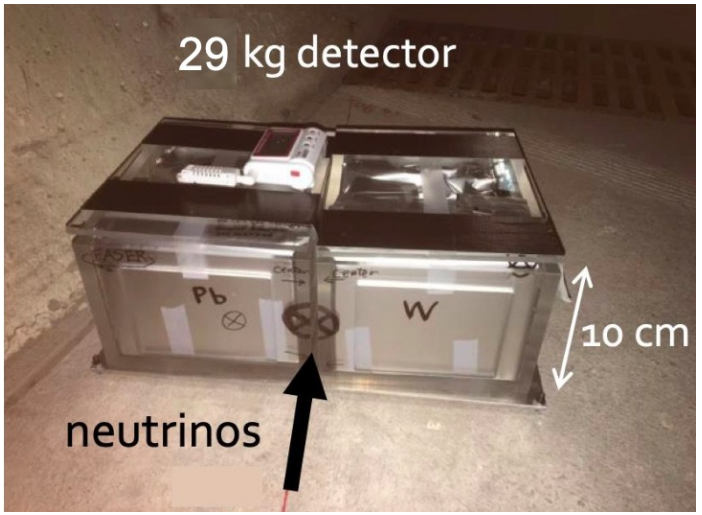
- Tracker: Custom General purpose I/O (GPIO) board
- Scintillator and Calorimeter: CAEN digitiser
- Trigger: Custom GPIO board
  - 500 Hz expected rate (dominant by muon flux, 1 Hz/cm2 for L=2×1034 cm-2s-1)
  - Clock and bunch taken from LHC



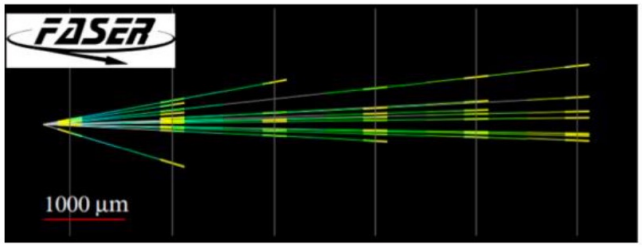
- Ethernet switch -> Servers on surface
- All components are installed and pass 1KHz test: 2021 JINST 16 P12028

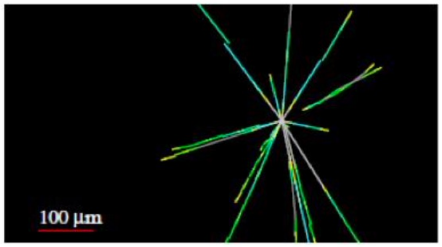
FASERν Emulsion/Tungsten

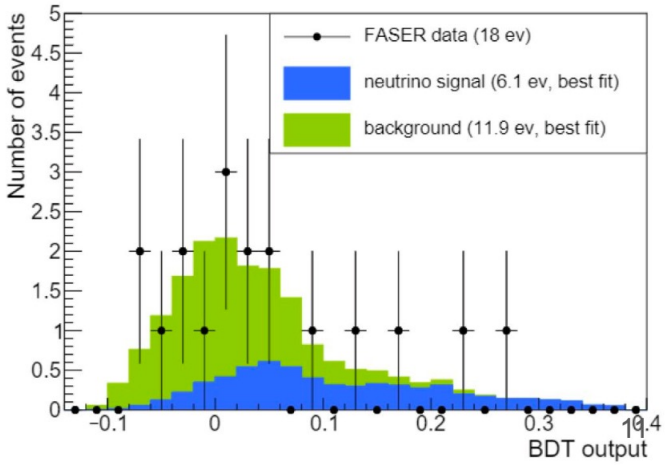
- Charged particle ionization recorded and can be amplified and fixed by chemical development of film
  - 770 emulsions interleaved with 1-mm-thick tungsten plates (1.1 tonnes)
  - Track position resolution ~50 nm
  - Angular resolution ~0.35 mrad
  - No Timing information



- Pilot detector (29 kg) exposed in TI18 for 1 month in 2018
  - Observed first collider ν candidates (2.7σ) with 12.2 fb-1 data!
  - Phys. ReV. D 104, L091101







Installation

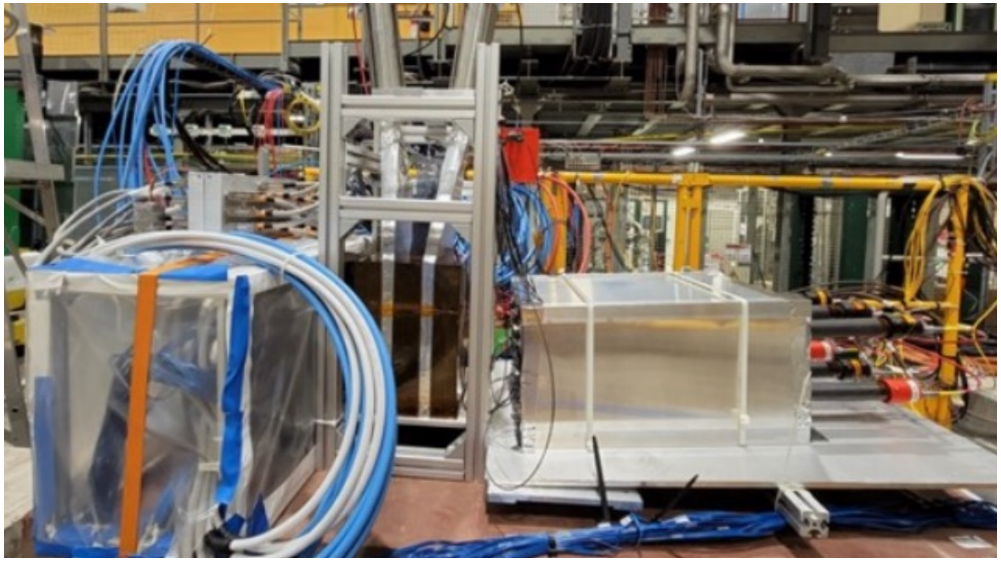
Installation

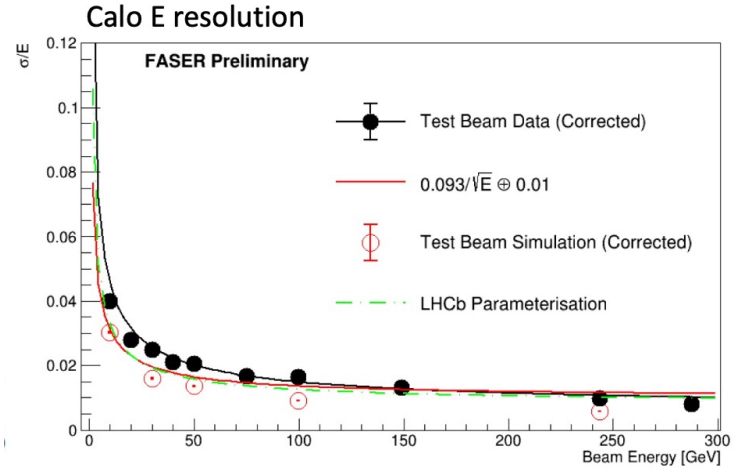
- Full Installation Video
  - https://faser.web.cern.ch/faser-installation
- Detector Paper
  - arxiv: 2207.11427

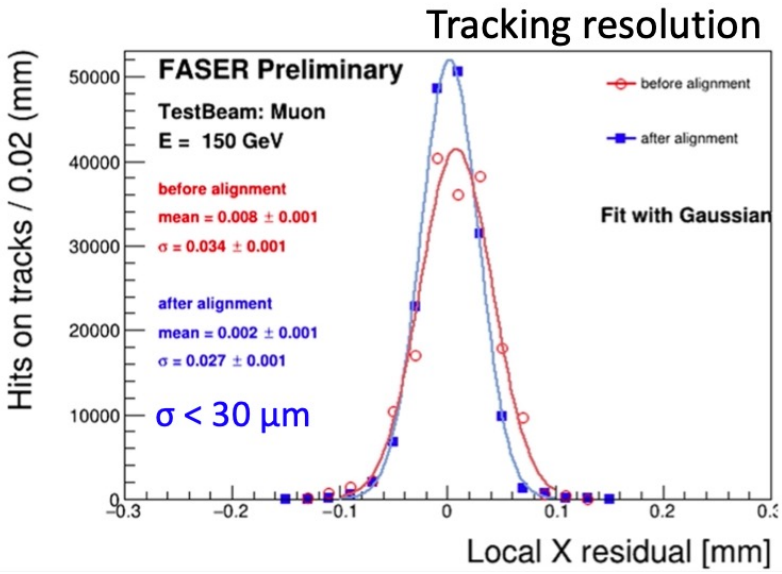
- Current partial (30%) FASERν
  - Frequent exchange in Run 3
  - 1st full detector July 26 (TS1)
  - 2nd full detector Sep 13 (TS2)

Test-Beam Measurements

- Test Beam @ CERN H2 beam (2021)
  - Electrons(5-300GeV),muons (200 GeV) and pions (200 GeV)
  - 6 ECAL modules (inc. spares)
  - Along with IFT and preshower
  - Paper in preparation

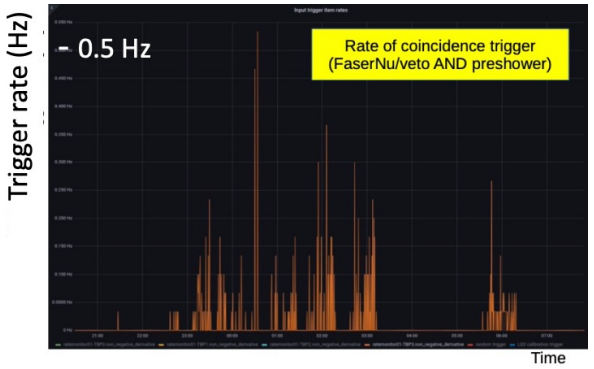


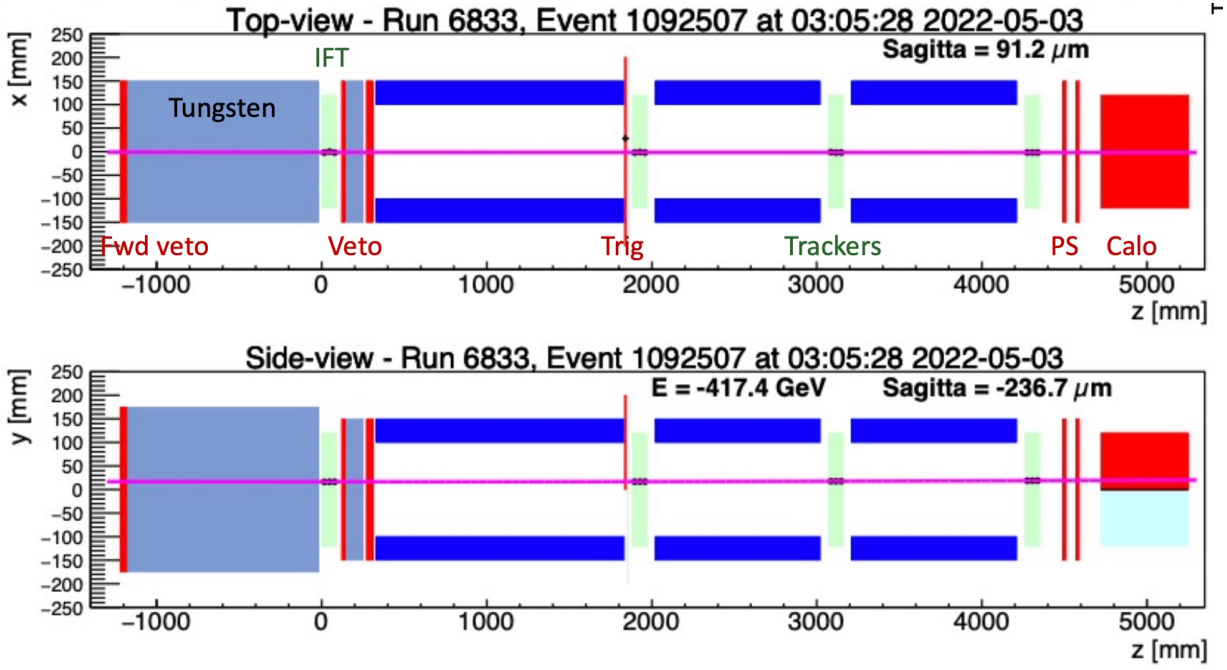


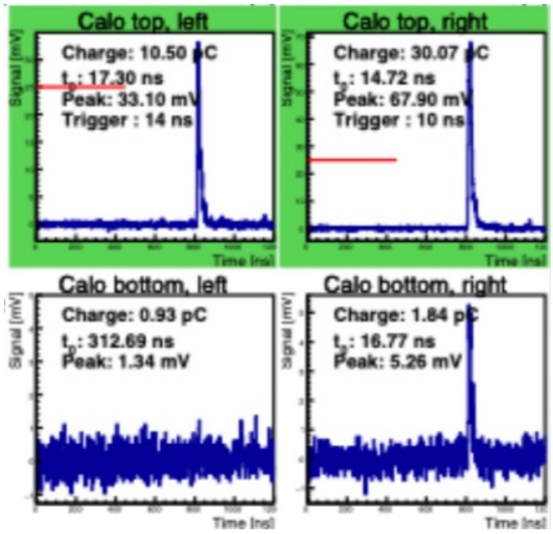


First Data

- Currently data-taking
- Saw first beam particles from recent 6.8 TeV beam optics tests First particles traversing full detector, including FwdVeto and IFT



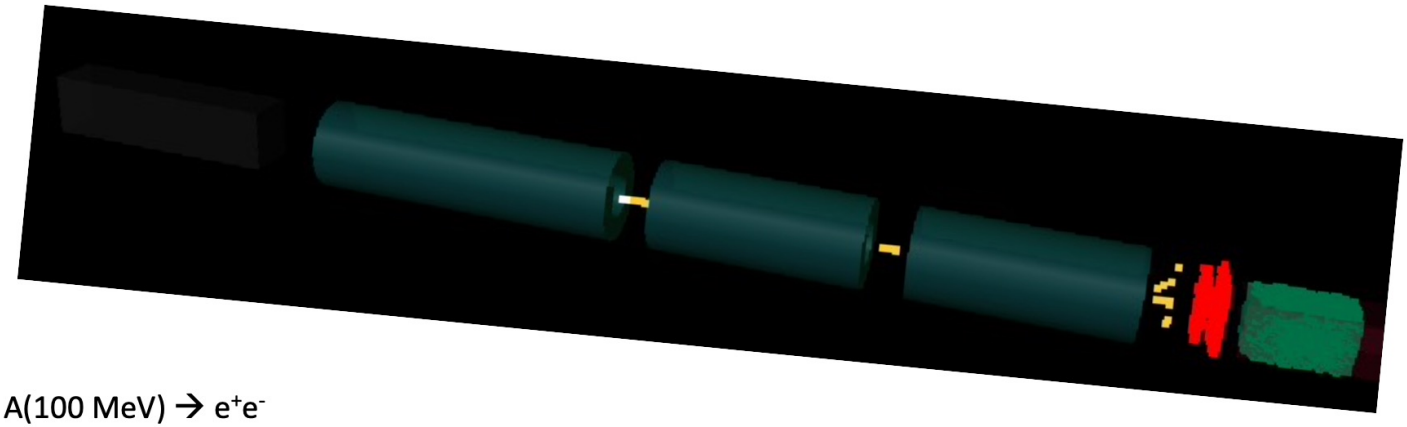




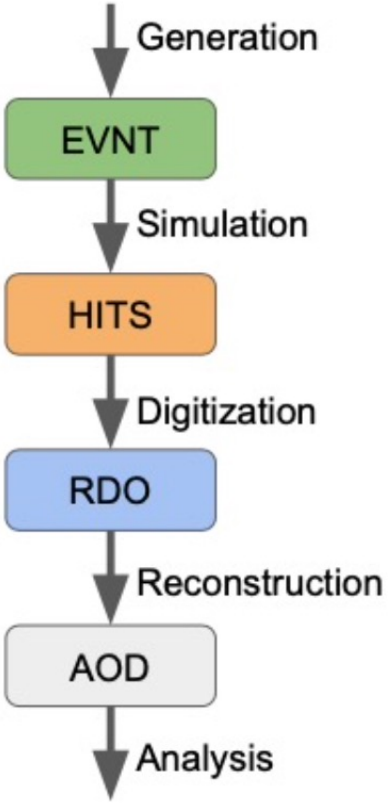
Mock Data Challenge

- Ongoing Mock Data Challenge (MDC) to ensure readiness for data-taking
  - Test full production chain from generation all the way through to analysis
  - Representative background and signal processes have been produced

- Goal: demonstrate end-to-end analysis workflow
  - Finalise software: determine readiness & find missin pieces
  - In addition, jump start analysis effort already

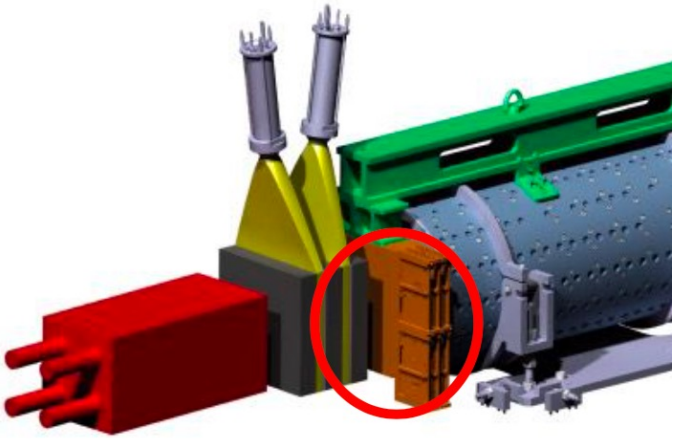


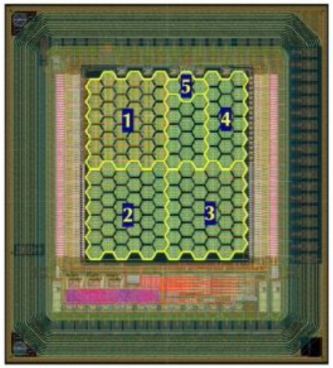
A(100 MeV) → e^+e^-



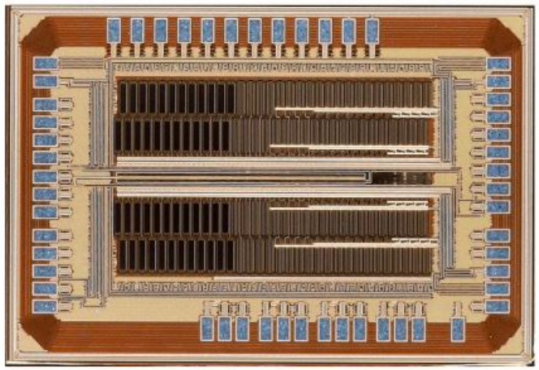
Preshower Upgrade (1/2)

- Upgrade for 2023/2024
  - Preshower scintillator will be replaced by hybrid pixel detector (100μm pitch, 130nm SiGe BiCMOS)
  - Upgrade to enable detecting ALPs→ $\gamma\gamma$ searches (2 photon separation by ~200μm)
  - Installation by the end of 2023, and data-taking from 2024
  - Approved by CERN. See TDR CERN-LHCC-2022-006

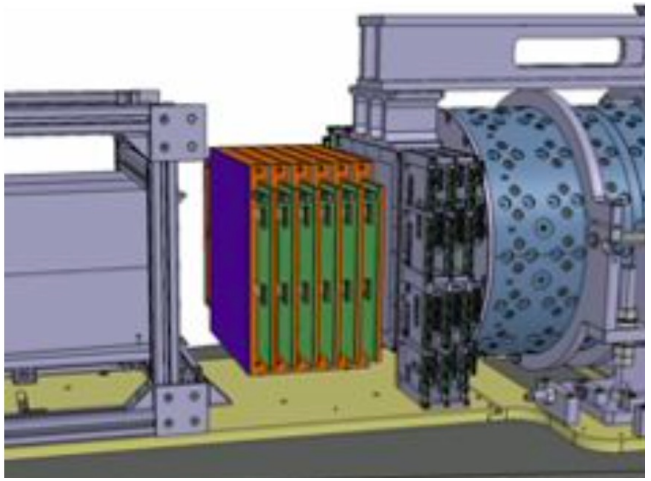




hexagonal pixels

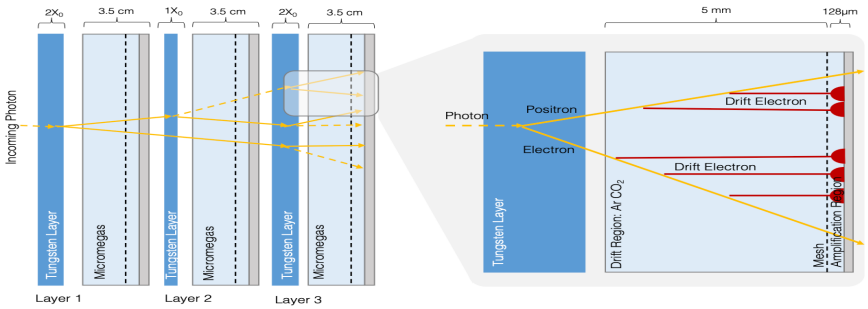


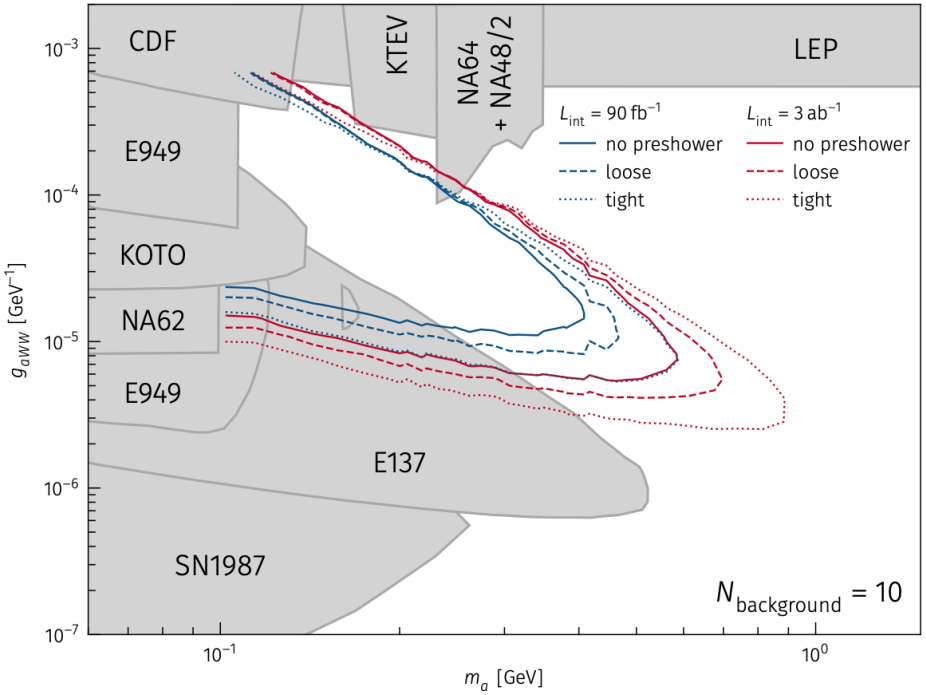
Prototype chip

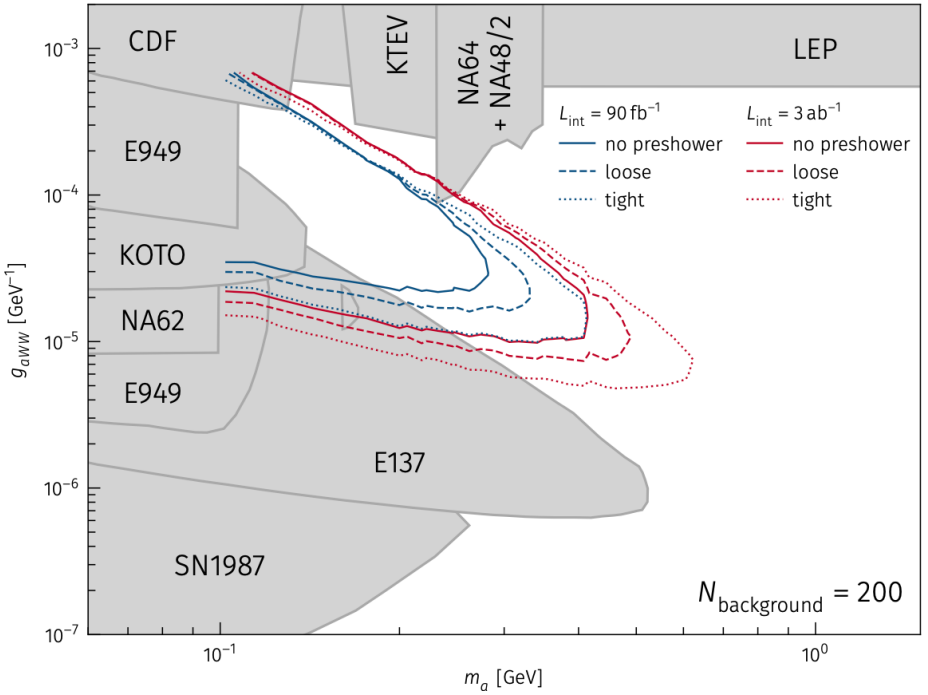


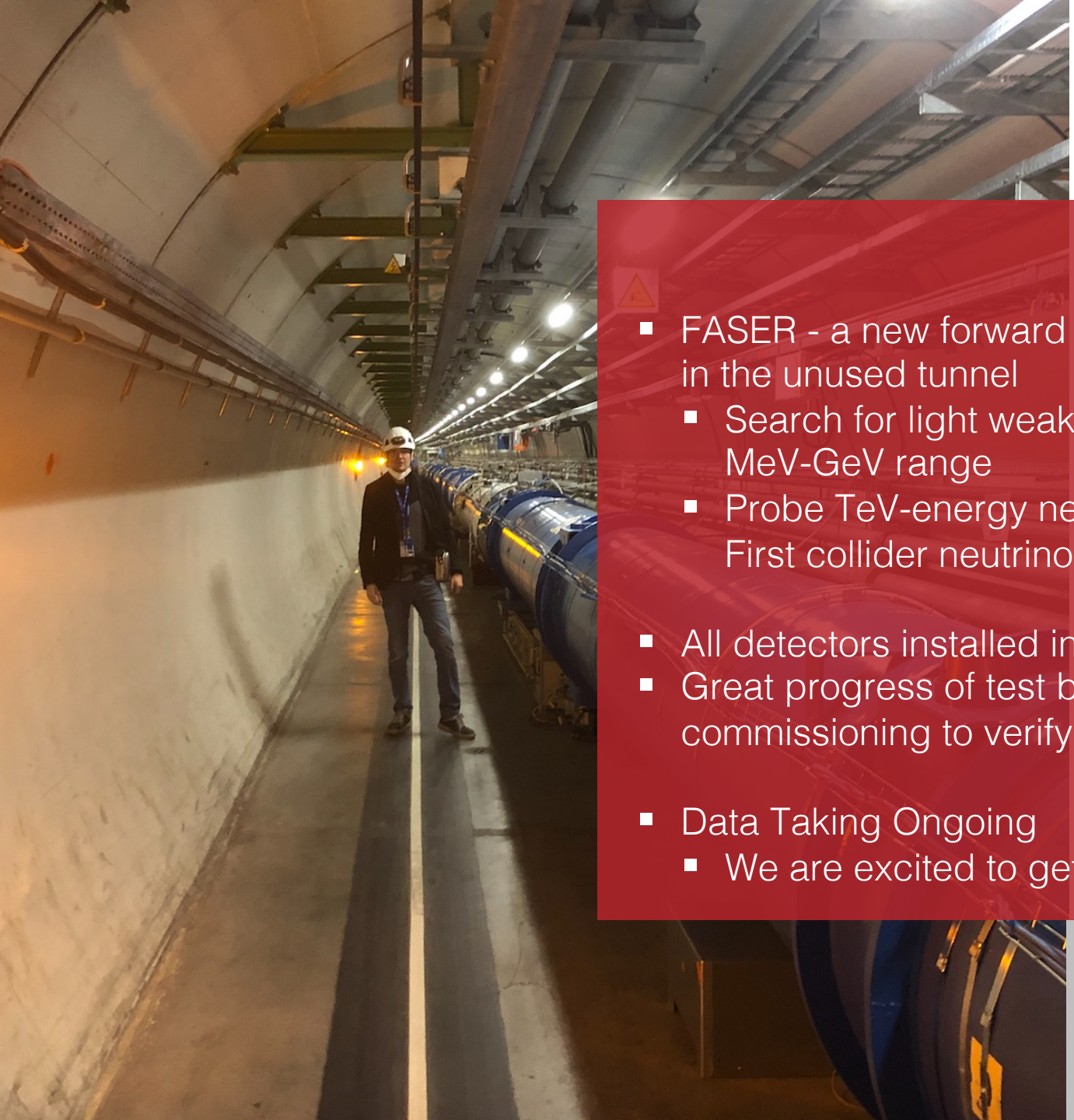
Preshower Upgrade (2/2)

- Alternative Concept developed in Mainz
  - Idea: Use Micromegas Detectors
  - [2111.14939.pdf]









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Summary

- FASER - a new forward experiment at the LHC in the unused tunnel
  - Search for light weakly-coupled particles in MeV-GeV range
  - Probe TeV-energy neutrino in all flavors - First collider neutrino candidate is published!

- All detectors installed in TI12
- Great progress of test beam analysis and commissioning to verify expected performance

- Data Taking Ongoing
  - We are excited to get our first physics results