Search for Weakly Interacting Particles with the FASER Experiment

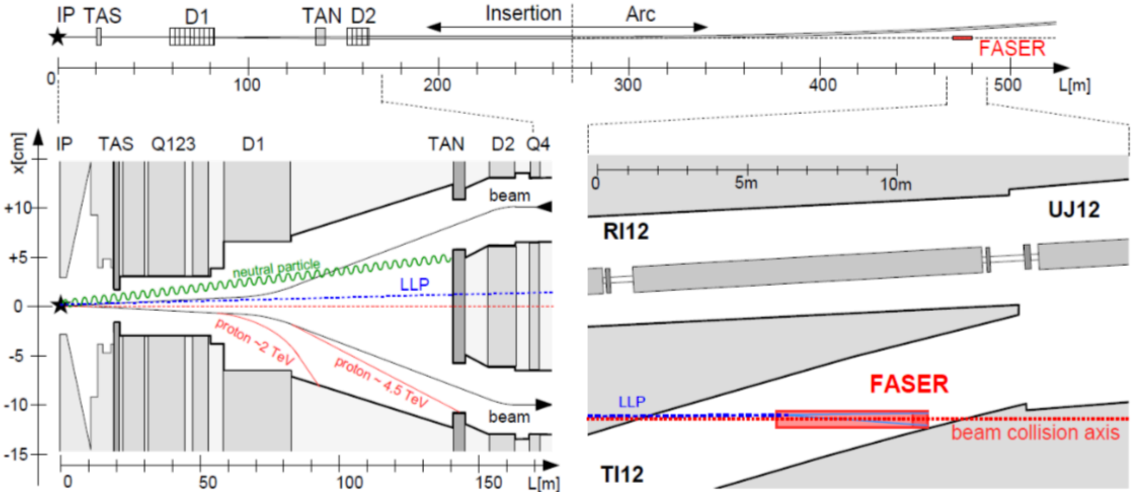
Matthias Schott on behalf of the FASER Collaboration

The general idea

- Huge cross-sections at the LHC
  - $N_{inel} \approx 2.3\times10^{16}$ 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.
- Example I: Dark Photon
  - $pp \rightarrow A'X$ (here many possible production mechanism)
    - $\pi^0 \rightarrow A'\gamma$
  - A' travels ~O(100)m,
  - $A' \rightarrow e^+e^-, \mu^+\mu^-$
- Example II: ALPS
  - dominant production mechanism is Primakoff process $\gamma N \rightarrow aN'X$ of high energetic photons interacting with the LHC infrastructure
  - 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.

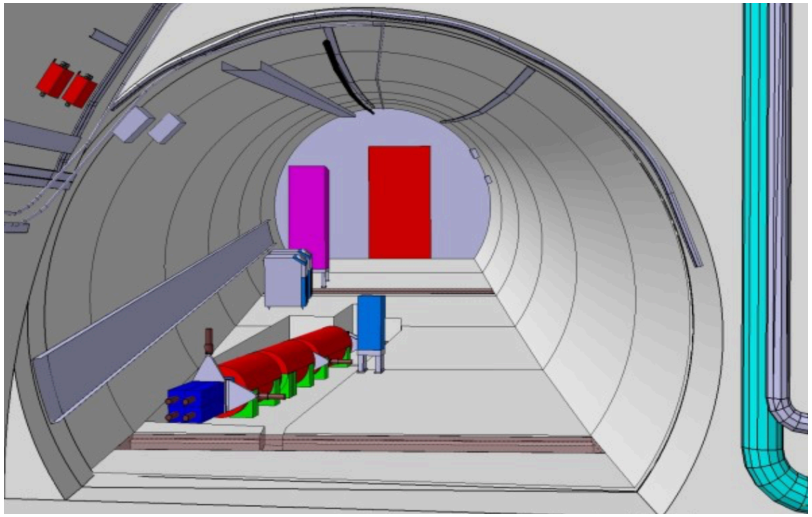
Experimental Site

- 480m from ATLAS collision point (TI12).
- Transfer line connecting SPS and LHC tunnels used for LEP, but now unused
- Limited space
  - The floor of the tunnel needs to be lowered by <50 cm
  - install FASER detector on the beam collision axis

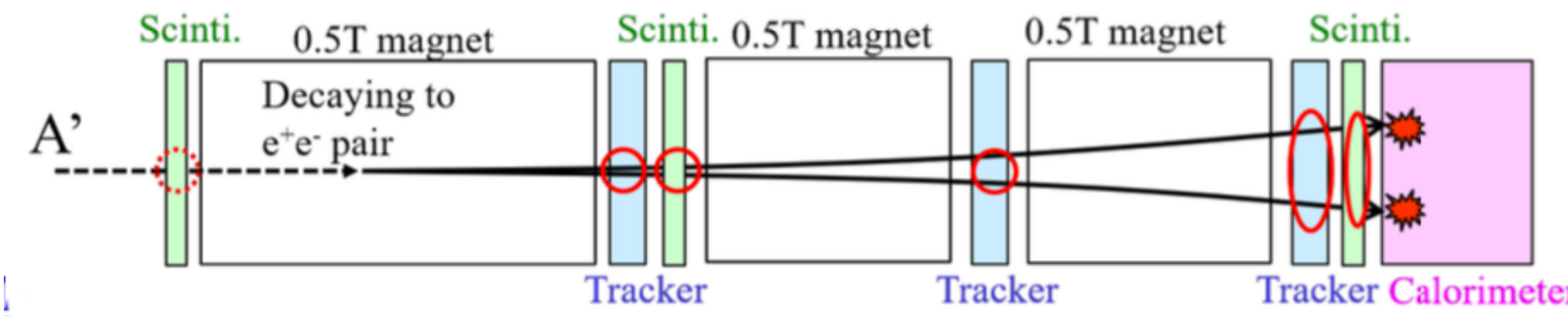


FASER Experiment

- ForwArd Search ExpeRiment at the LHC
- Low cost
  - Small detector (r=10 cm, 5 m long).
  - The detectors developed for other experiments will be recycled as much as possible (tracker, calo, DAQ).
  - Construction cost: <1MCHF
- Quick!
  - Aim to construct the detector during LS2 and start data-taking in 2021
  - It is big advantage to use detectors that are already used
- Excellent sensitivity!
  - FASER will explore large parameter space of new particles



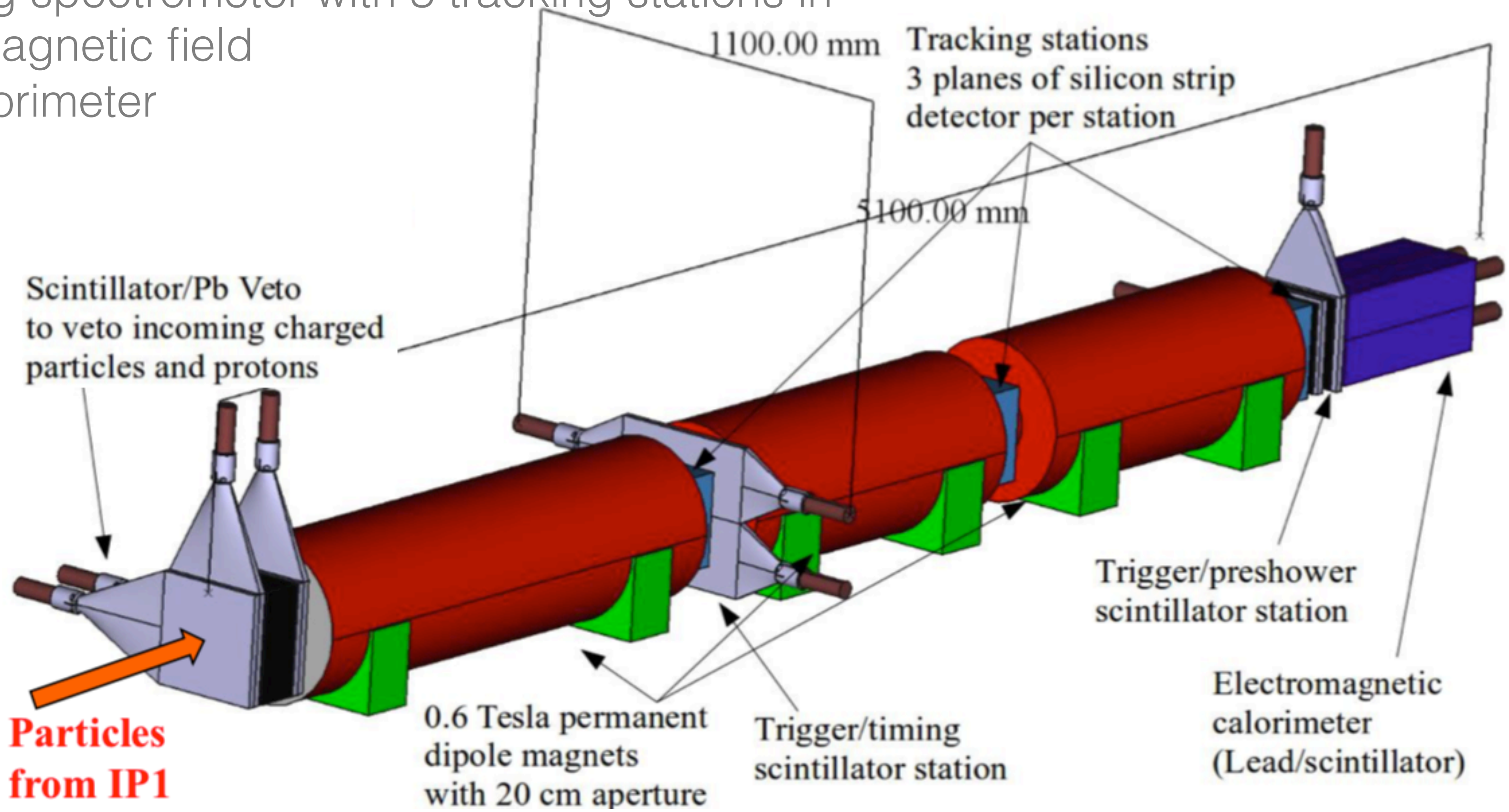
Signal and Backgrounds



- Signal: two e^+e^- tracks (or 2γ) originating from a new particles
  - 150 fb^{-1}@Run3
- Rocks and LHC shielding eliminates most potential backgrounds.
- High energetic muons and neutrinos are the main backgrounds.
  - ~100Hz of muons going through the tracker
  - 80k muon events with γ or EM/HD shower
  - A few (~100 GeV) CC/NC neutrino events
- Can be reduced to negligible level, assuming charged particle veto with efficiency of 99.99%

Detector Concept

- The detector consists of:
  - Scintillator veto/trigger
  - 1.5m-long decay vol. 0.5-0.6 T magnetic field
  - 2m-long spectrometer with 3 tracking stations in 0.5 T magnetic field
  - EM calorimeter



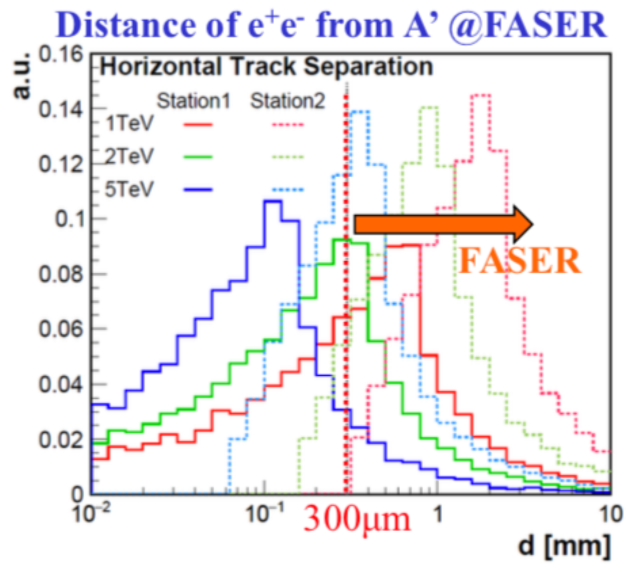
The Spectrometer

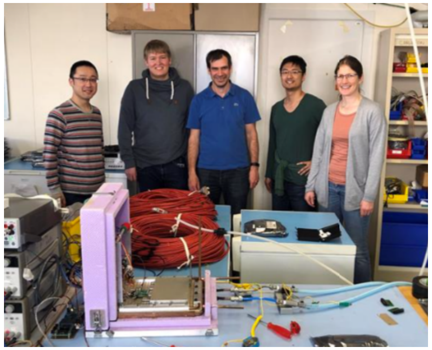
- Permanent magnet with ~0.5 T will be used for e^+e^- separation.

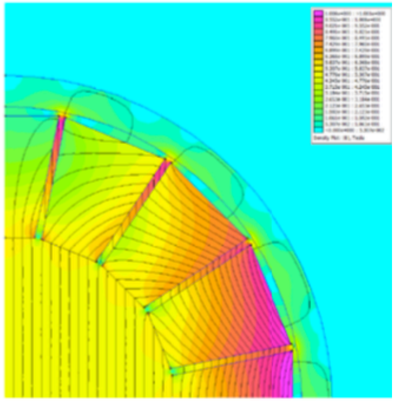
- The magnet will be constructed by the CERN magnet group.

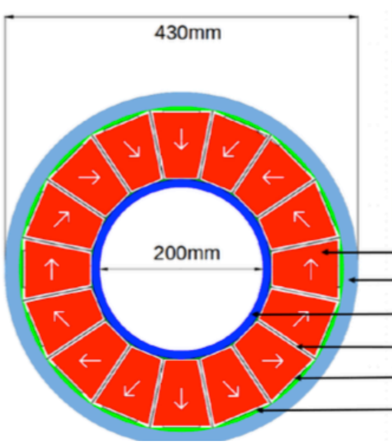
- The spectrometer needs to identify two tracks from $A' \rightarrow e^+e^-$ with >300 μm distance ($m_{A'}$ = 100 MeV).

- Silicon strip detector will be used for the tracker







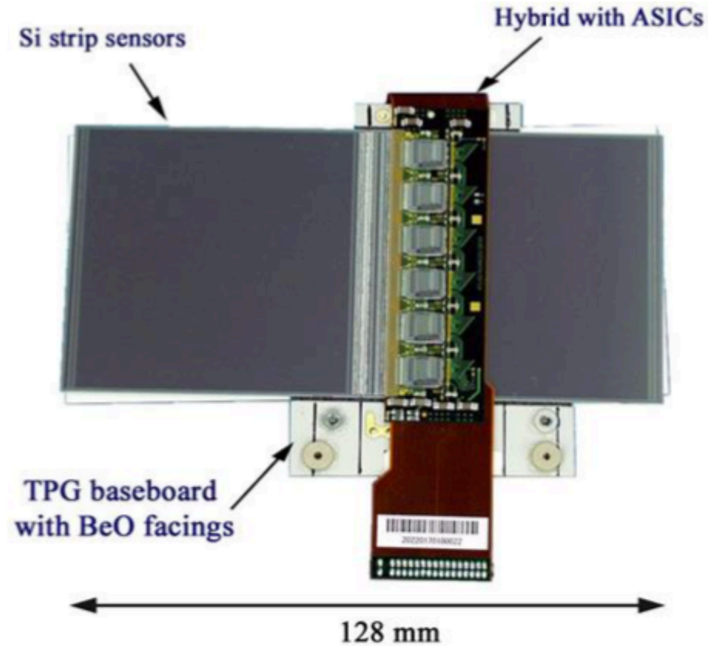


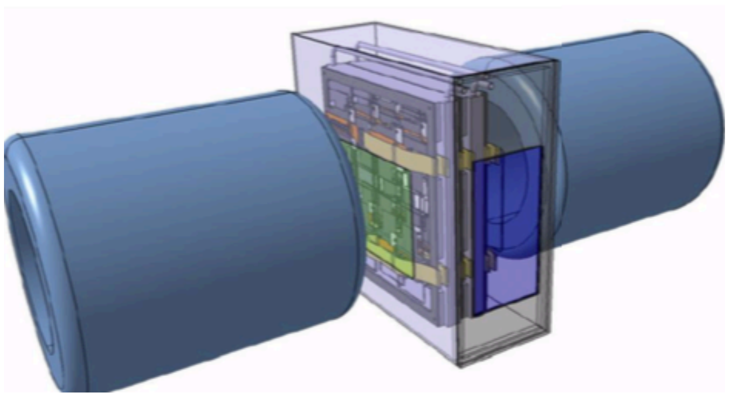
Tracker

- 80 spare ATLAS SCT barrel modules will be used for FASER tracker.
  - Thanks to ATLAS SCT collaboration!
  - 80 μm pitch with 12.8 cm length.

- FASER tracker consists of 3 stations each with 3 SCT layers
  - One layer consists of 8 SCT modules.

- Quality assurance test was performed.
  - 80 modules were already selected for FASER tracker.



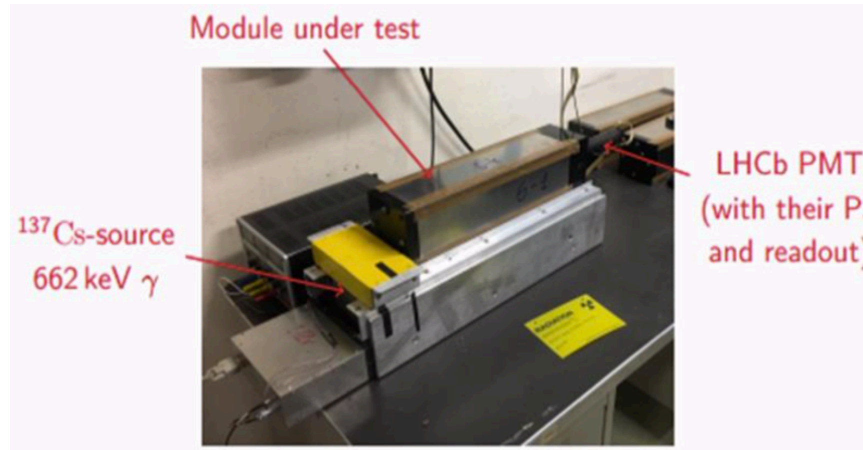


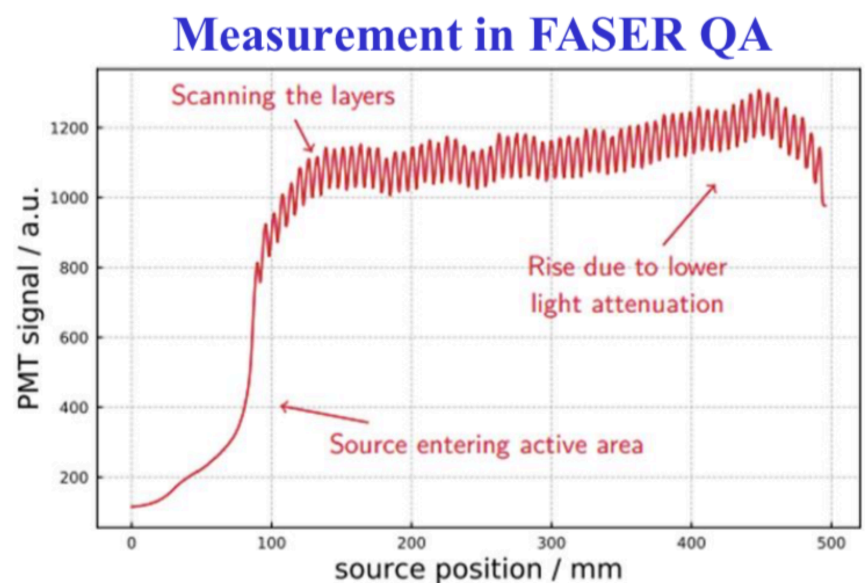
Calorimeter

- FASER EM calorimeter for measuring EM energy, electron/photon identification, Trigger.
  - 4 spare LHCb outer ECAL modules will be used.
  - Thanks to LHCb for letting us use these modules!

- 66 layers of lead/scintillator (25 radiation length), light out by wavelength shifting fibers.

- ~1% energy reso. for 1TeV electrons.



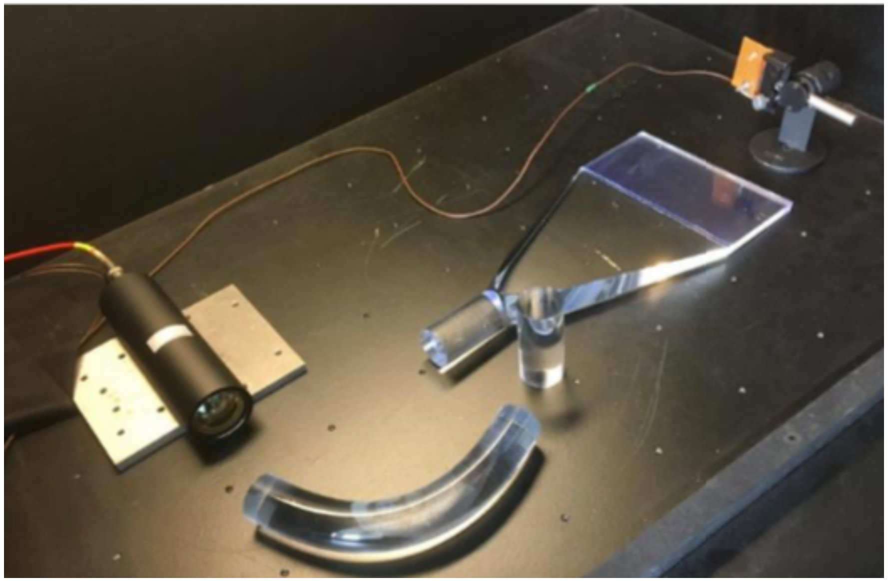


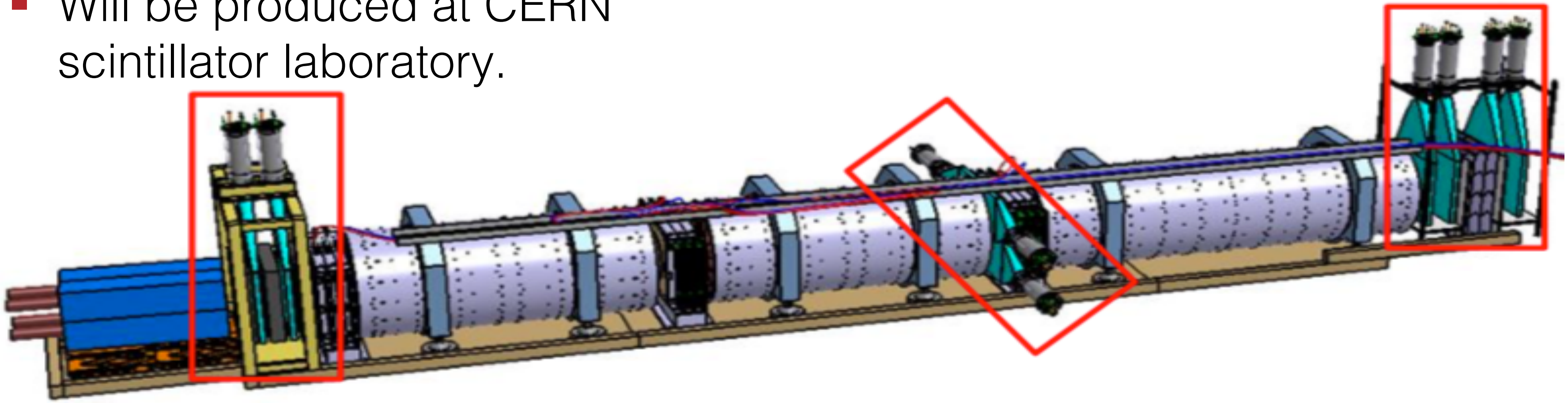
Scintillator

- Scintillator detectors for
  - Creating a trigger signal.
  - Vetoing charged particles entering the decay volume.

- Require extremely efficient charged particle veto (>99.99%).
  - Important for BG suppression.
  - achieved by 4 layers of scintillators

- Will be produced at CERN scintillator laboratory.



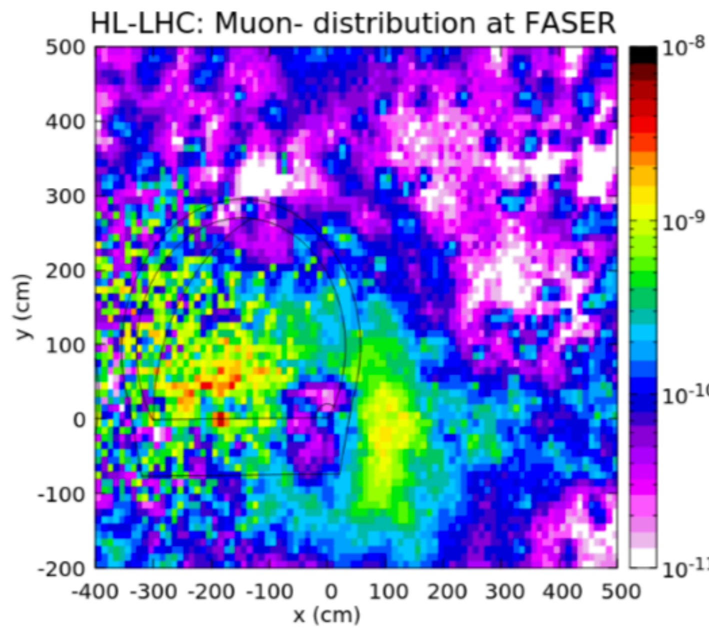


Muon Flux and other backgrounds

- The muon flux at FASER site was evaluated with FLUKA.

- Due to bending from LHC magnets, muon flux on line-of-sight (LOS) is reduced.
  - μ^- tend to be bent to the left and μ^+ to the right of FASER
  - FASER site is perfect place to escape from muons from IP1!

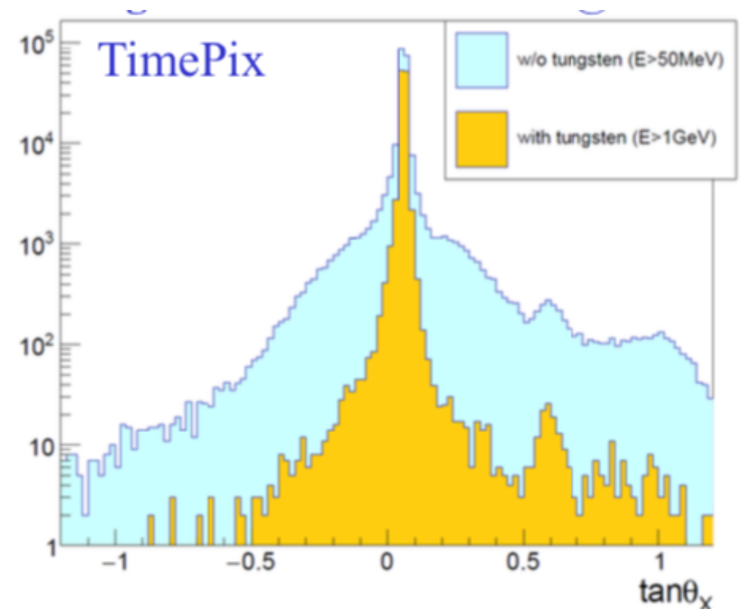
- Background for ALP searches: high energy neutrino's interacting in the calorimeter to give large EM showers
  - either muon neutrinos leading to hadronic showers with π^0,
  - or (more rarely) electron neutrinos interacting to give electrons



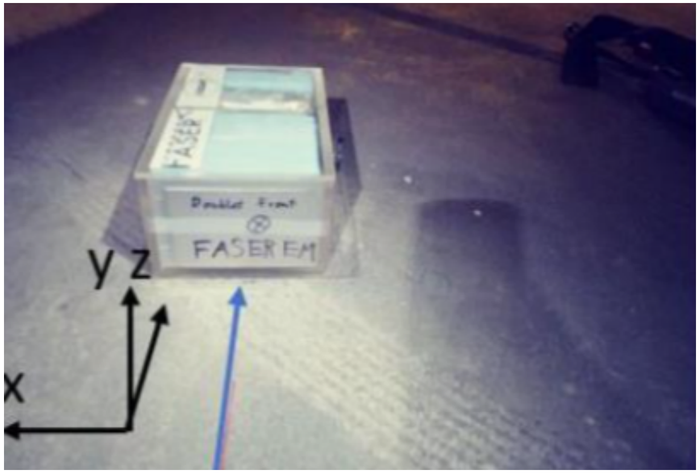
Energy threshold [GeV]	Charged particle flux [cm^{-2} s^{-1}]
10	0.40
100	0.20
1000	0.06

Beam Backgrounds and Radiations

- Beam background
  - The emulsion detector and TimePix beam loss monitor were installed at TI12 in 2018 to measure particle flux.
  - The results were consistent with FLUKA expectation.
  - Detailed study is ongoing.

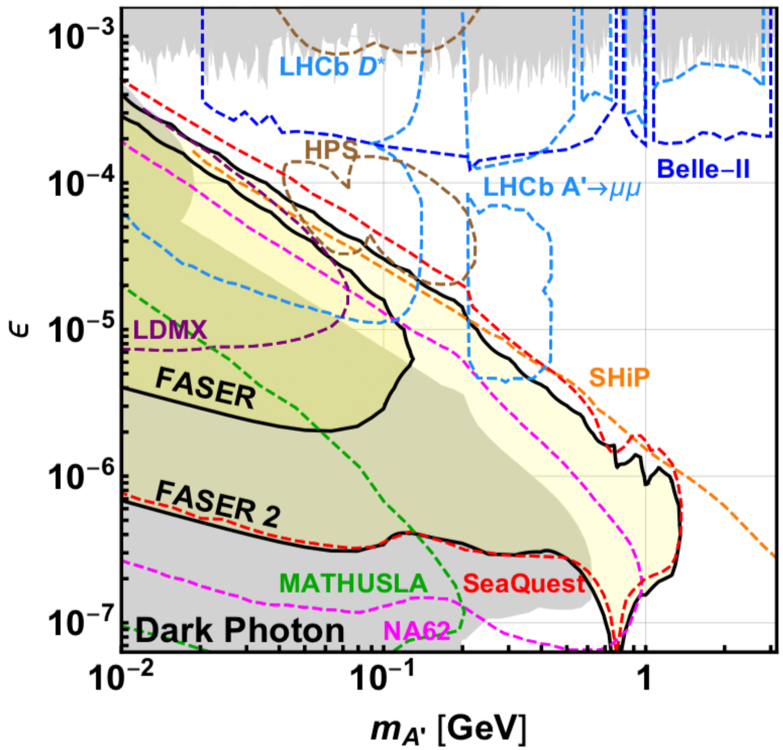


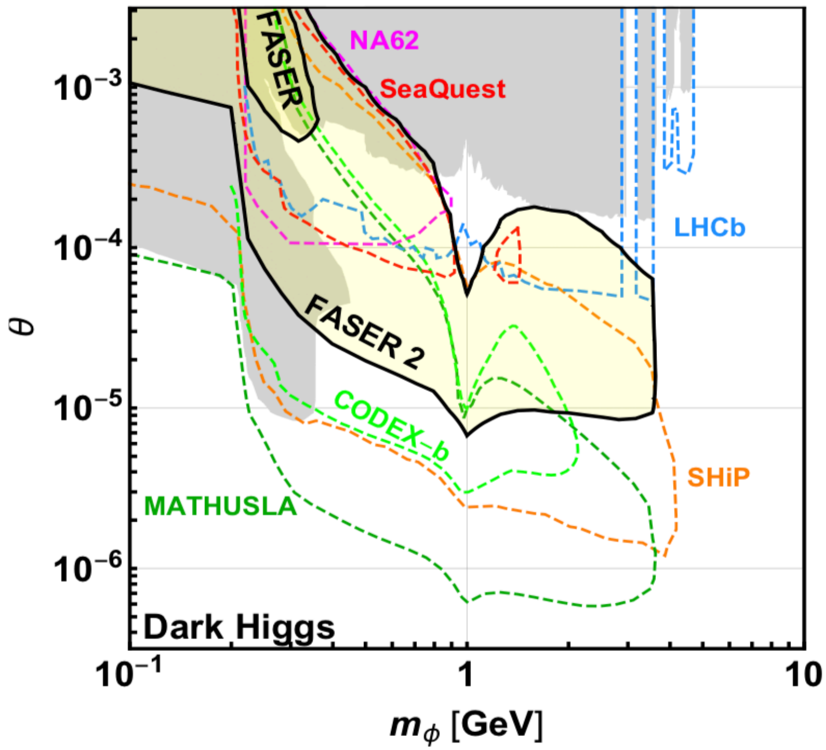
- Radiation: FLUKA expectation was confirmed by measurement with BatMon detector:
  - <5 x 10-3 Gy/year
  - <5 x 107 1 MeV neq/year



- Conclusion: FASER does not need radiation hard electronics.

Physics Reach: Dark Photons and Dark Higgs

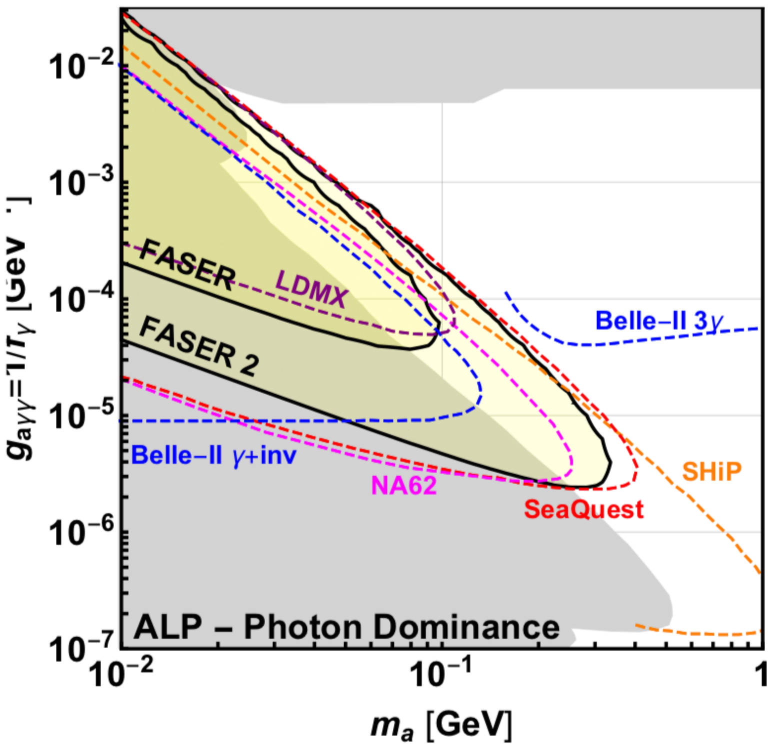




- FASER has sensitivity to coupling strength of ~10^{-5} for dark photon.
  - Assumption: 0 background and 100% efficiency.
  - →FASER, LHCb and Belle2 are complementary and can cover most search region of $m_{A'}$ < 1GeV
  - FASER 2 - possible future upgrade with 1m radius and 3000/fb of data.

Physics Reach: Heavy Neutral Leptons and ALPs

- 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)
  - Preliminary studies suggest that events with no tracks and a large EM energy in the calorimeter would be ~background free
    - an ALP signal would be detectable without the need to resolve the 2 photons.



- 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.

Schedule towards data-taking

- Documentation and approval
  - Letter Of Intent (LOI) was submitted to LHCC in July 2018 (arXiv:1811.10243).
  - Technical Proposal (TP) was submitted to LHCC in November 2018 (arXiv:1812:09139)
  - The experiment was approved by CERN at Research Board on March 5th 2019.

- Funding for detector construction/ operation was secured from Simons Foundation and Heising-Simons Foundations.

- Timeline
  - Construction/Comm. is planned during LS2.
  - Detector installation is foreseen in May 2020.
  - Data-taking will start from 2021, synchronizing with LHC Run3.

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Summary

- FASER will search for new light particles coming from ATLAS pp collision point (IP1)
  - can explore uncovered parameter space, and is complementary with searches by LHCb and Belle2.
- The detector will be installed at 480 m away from IP1 where SPS and LHC rings are connected and is based on spare LHC experiment detector components
- Workintensive years ahead to get everything ready in time