FASER

Forw**A**rd **S**earch **E**xpe**R**iment at the LHC

’19 5/29 Yosuke Takubo (KEK)

On behalf of FASER Collaboration

Supported by:

HEISING-SIMONS FOUNDATION

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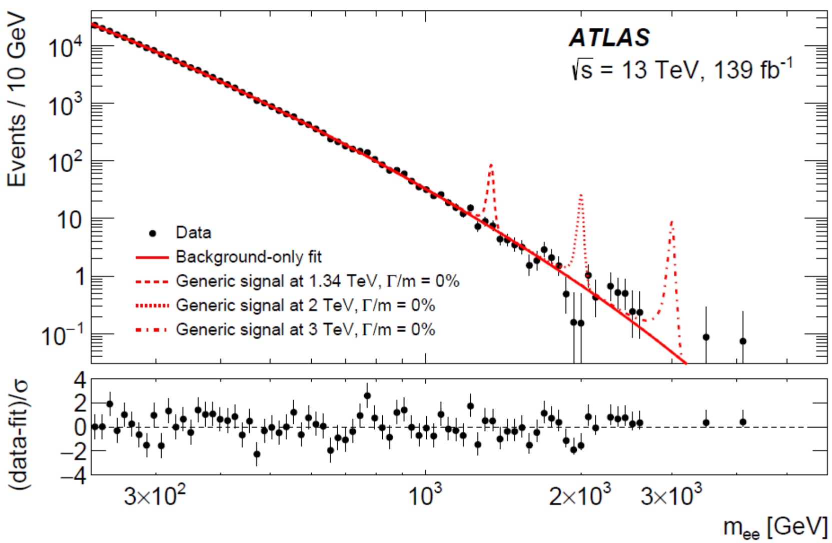
Fifth workshop of the LHC LLP Community @ CERN

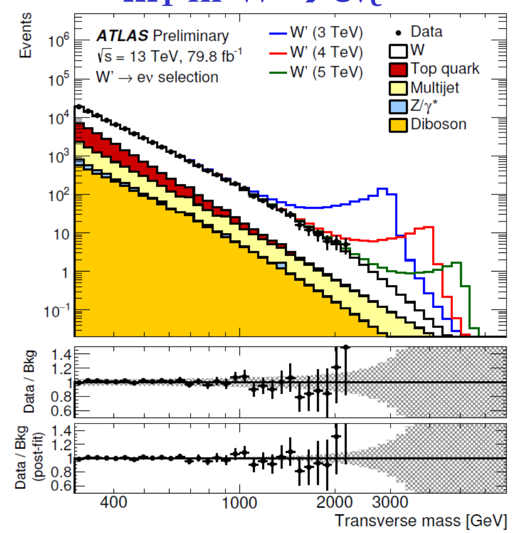
New particle search in LHC

- ATLAS and CMS search for new particles in Beyond the Standard Model (BSM), focusing on those with heavy masses and high pT.
- No evidence of such new particles is detected so far.

Di-electron mass in Z'→ee



m_T in W'→eν_e

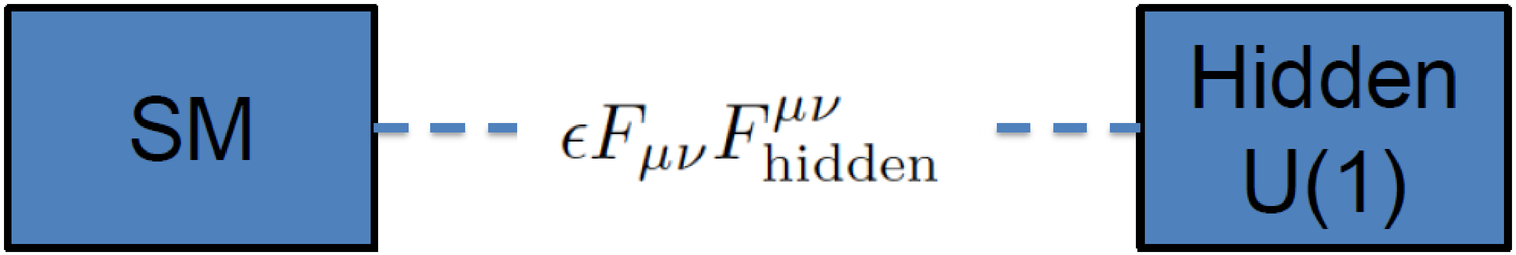


- If new particles are light and weakly interacting to SM particles, they are long-lived and could be collimated in the very forward region.

➡ The detector should be placed at the forward region with long distance from the interaction point.

New particle in dark sector

- Dark matter is our most solid evidence for new particles. In recent years, the idea of dark matter has been generalized to dark sectors.
- Dark sectors motivate light and weakly coupled particles.
  - WIMPless miracle, SIMP miracle, small-scale structure, ….
- A prominent example: vector portal, leading to dark photons.
  - Induced by broken U(1) symmetry in hidden sector.

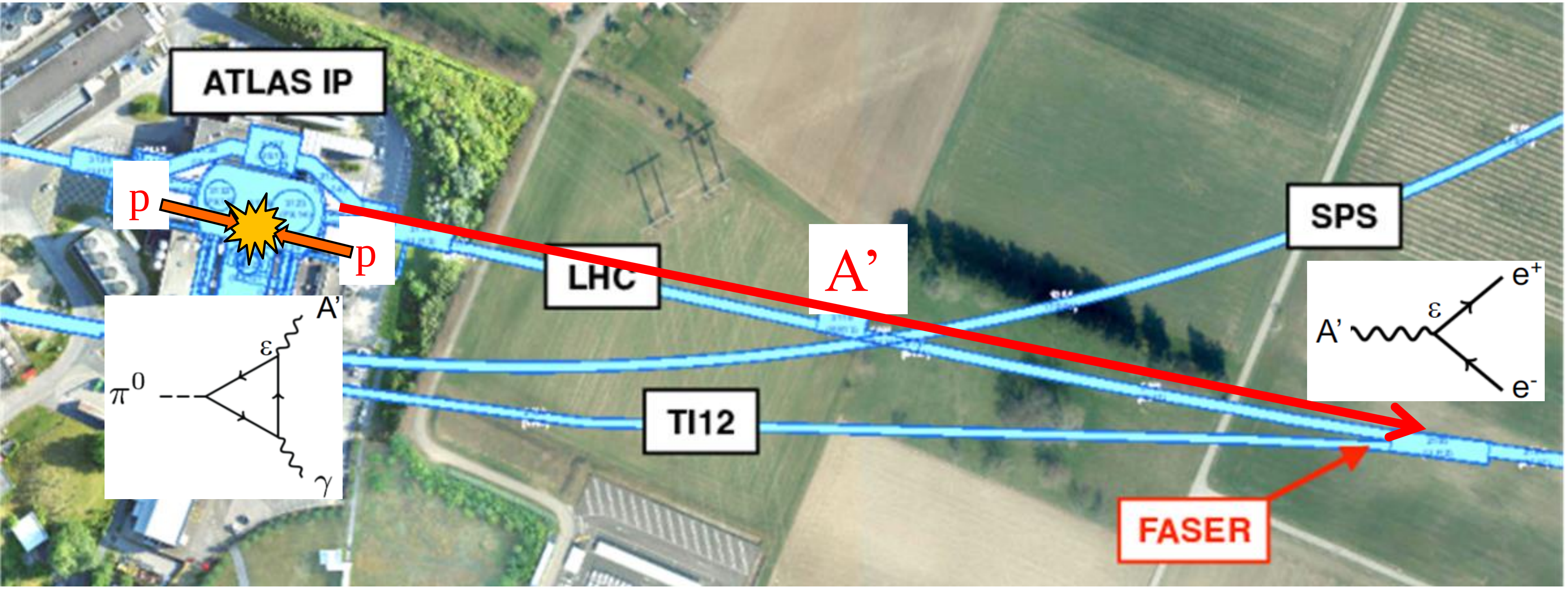


- The resulting theory contains a new gauge boson A' with light mass and its couplings to SM fermions.

Detection of new light particles (1)

- As the benchmark, consider about detection of dark photon with ($m_{A'}$=100MeV, $\varepsilon=10^{-5}$) (ε: coupling strength of A')
- The dark photons can be created by $\pi^0 \rightarrow A'\gamma$ process.

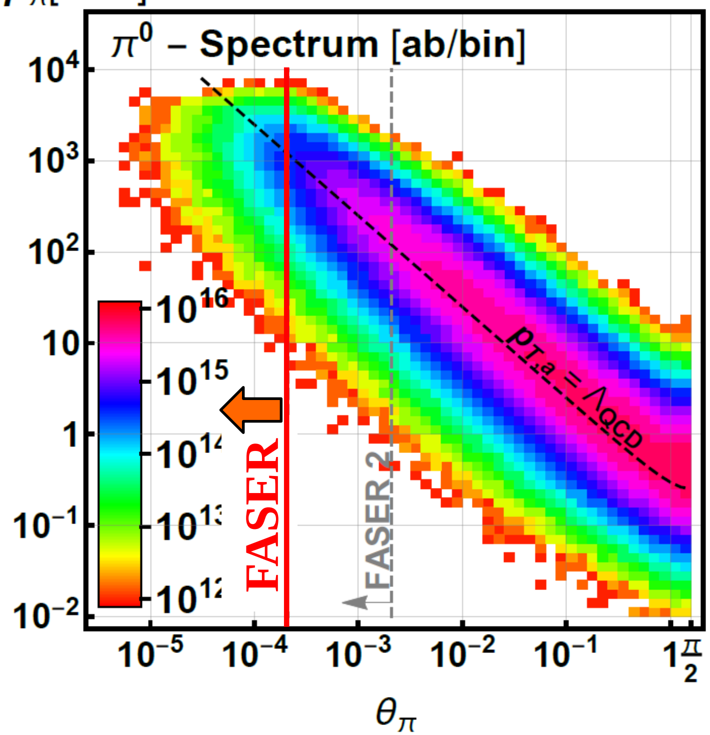
➡ Let's discuss about possibility to detect two electrons from $A' \rightarrow e^+e^-$ decays at 480 m distance from the collision point of ATLAS (IP1).



Detection of new light particles (2)

Assume the detector with 20 cm diameter and 5 m long, placed at 480 m away from IP1.

Pion dist. produced at IP1



1. ~2.3x10^{17} π^0s will be produced for 150 fb^{-1} in Run3.

2. 0.6% of π^0s are contained within the detector acceptance.

3. BR($\pi^0 \rightarrow$ A'γ) is suppressed by $\varepsilon^2 = 10^{-10}$.

4. Detector acceptance for A'→e^+e^-: ~10^{-3}

[2.3x10^{17}] x [0.6%] x [10^{-10}] x [10^{-3}]

~ 100 events can be detected by a detector with 20 cm diameter and 5 m long!

FASER experimental concept

Low cost!

- Small detector (20 cm diameter, 5 m long).
- The detectors developed for other experiments will be recycled as much as possible (tracker, calorimeter, DAQ system).
- Construction cost: <1MCHF

Quick!

- Aim to construct the detector during LS2 and start data-taking at the beginning of Run3 (2021).
- It is big advantage to use detectors that are already used in other experiments and whose performance is already known.

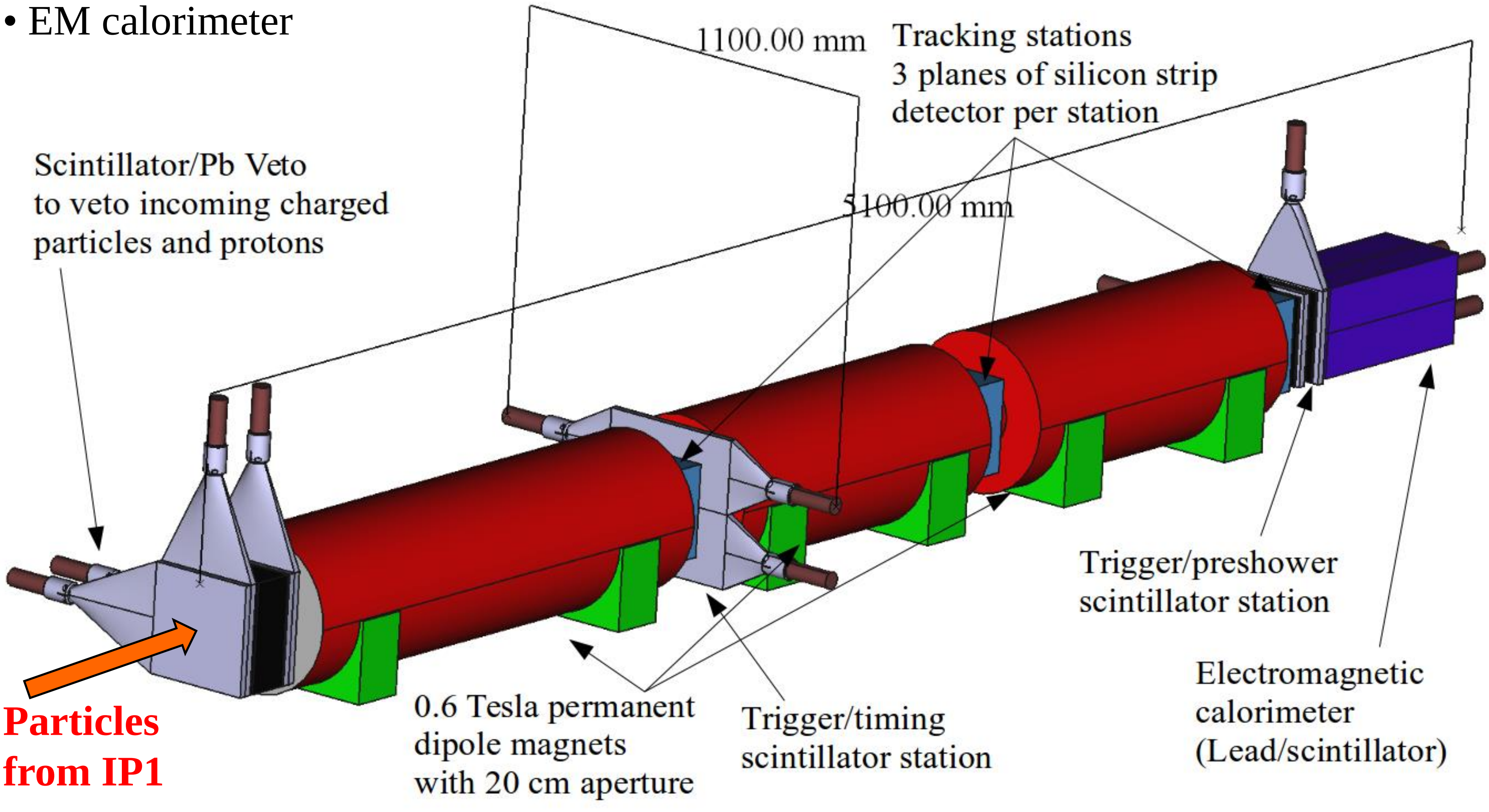
Excellent sensitivity!

- FASER will explore large parameter space of new particles which is not explored yet.

FASER detector

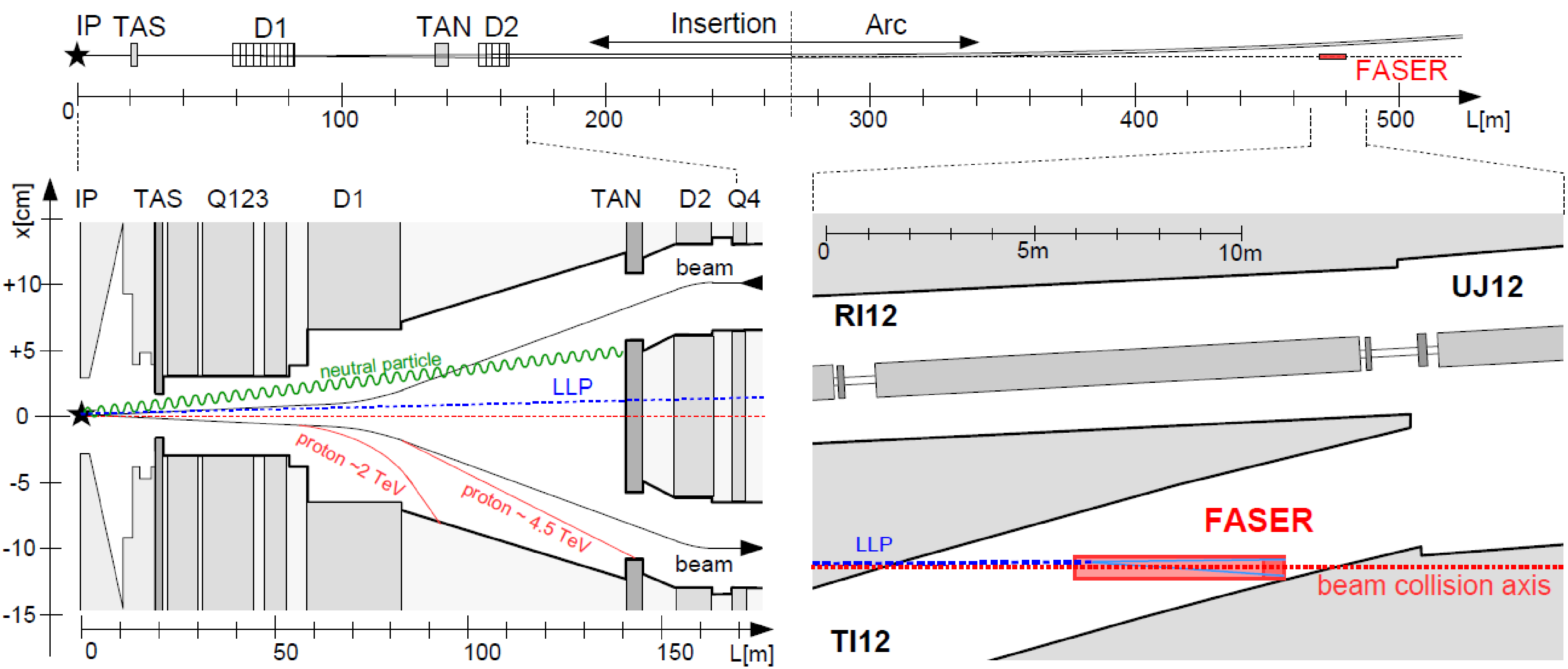
The detector consists of:

- Scintillator veto/trigger
- 1.5m-long decay vol. w/ 0.5 T magnetic field
- 2m-long spectrometer with 3 tracking stations in 0.5 T magnetic field
- EM calorimeter



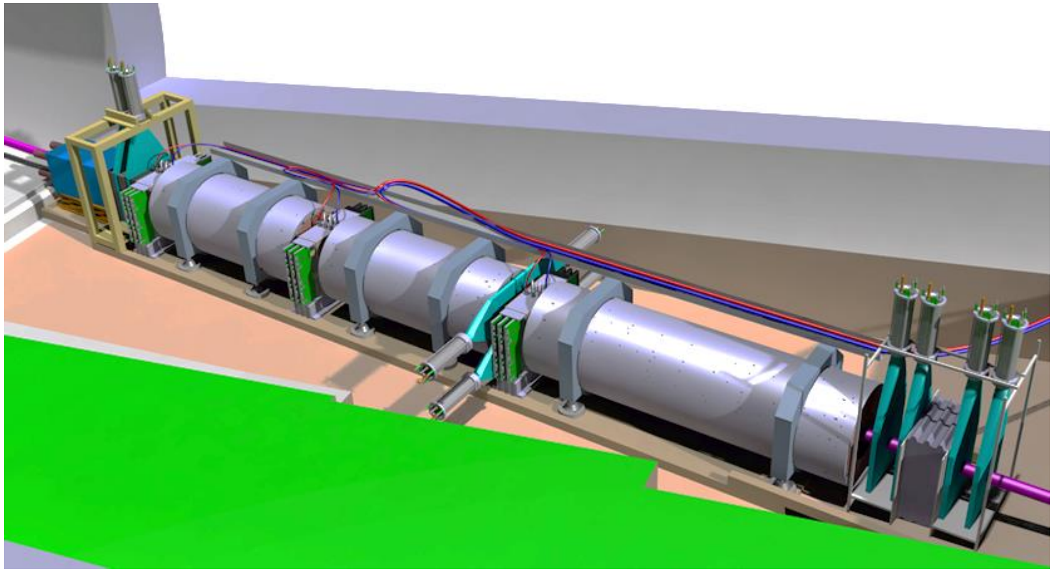
FASER site (1)

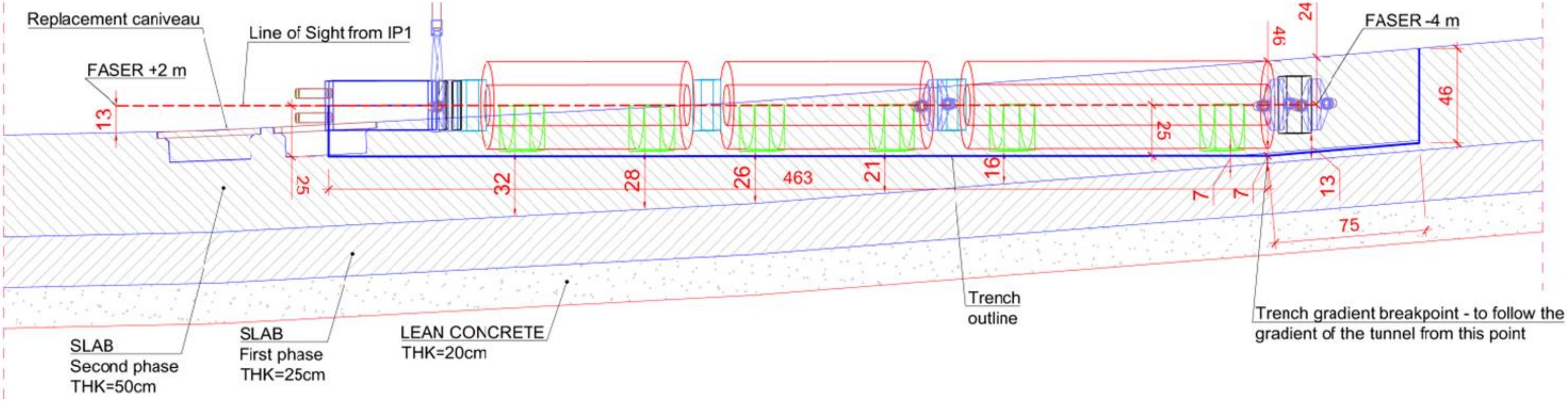
- 480 m from ATLAS collision point (TI12).
- Transfer line connecting SPS and LHC tunnels used for LEP, but now unused.



FASER site (2)

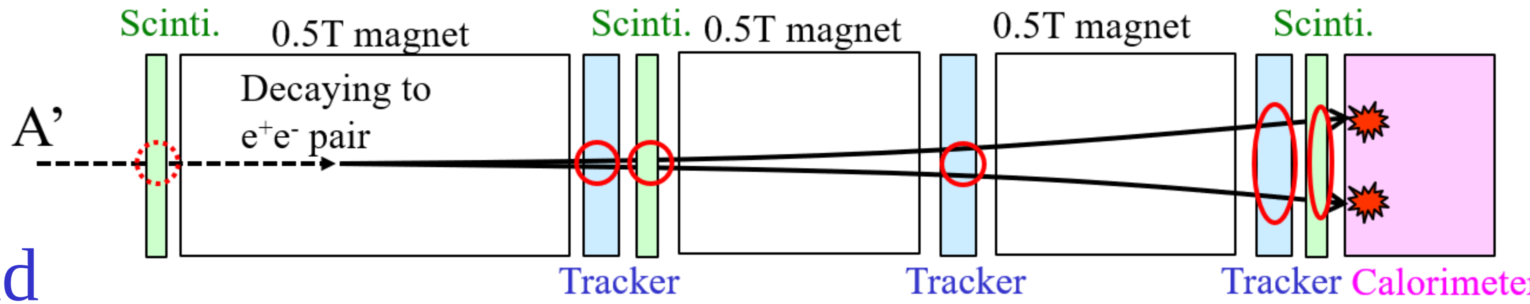
- The floor of the tunnel will be lowered by <50 cm in order to install FASER detector on the beam collision axis LOS (Line On Sight).
- Detailed study is ongoing by CERN civil engineering department.





Signal & Background in FASER

Signal: two e^+e^- tracks originated from a new particles



Background

- Natural rock and LHC shielding eliminates most potential backgrounds.
- High energetic muons and neutrinos are the main backgrounds.
  - ~100 Hz of muons going through the tracker
  - 80k muon events with γ or EM/HD shower
  - A few (~100 GeV) CC/NC neutrino events

} 150 fb^{-1} @Run3

(Possible neutrino measurement is under discussion)

Can be reduced to negligible level, assuming charged particle veto with efficiency of 99.99%

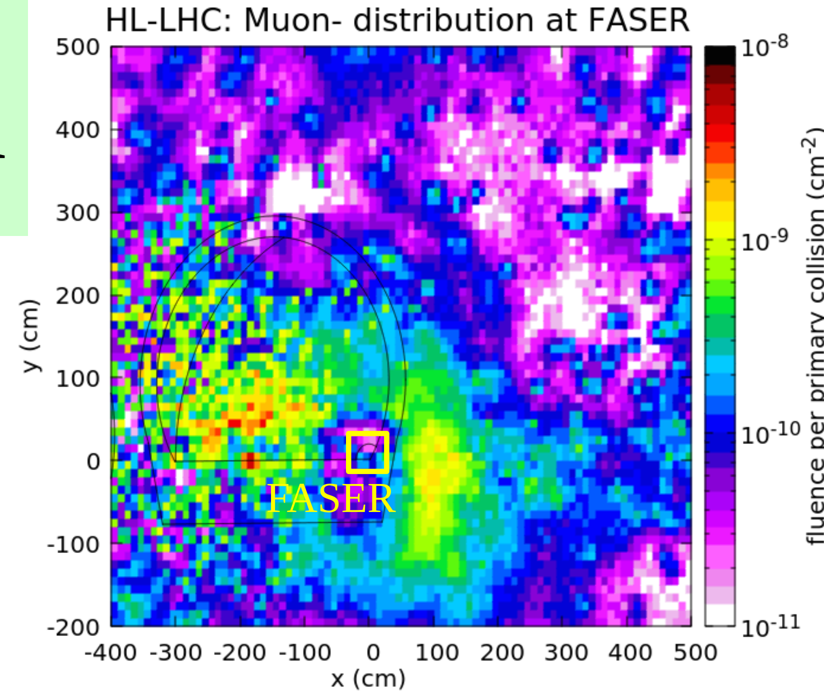
Muon flux expectation

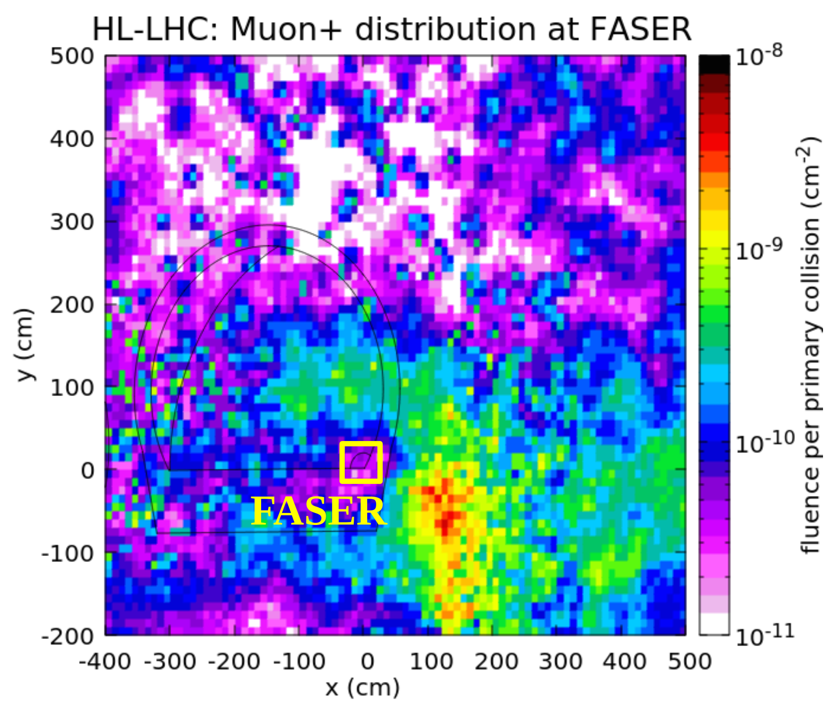
- The muon flux at FASER site was evaluated with FLUKA.
- Due to bending from LHC magnets, muon flux on LOS is reduced.
  - μ- tend to be bent to the left and μ+ to the right of FASER

➡ FASER site is perfect place to escape from muons from IP1!

Charged particle rate evaluated by FLUKA

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

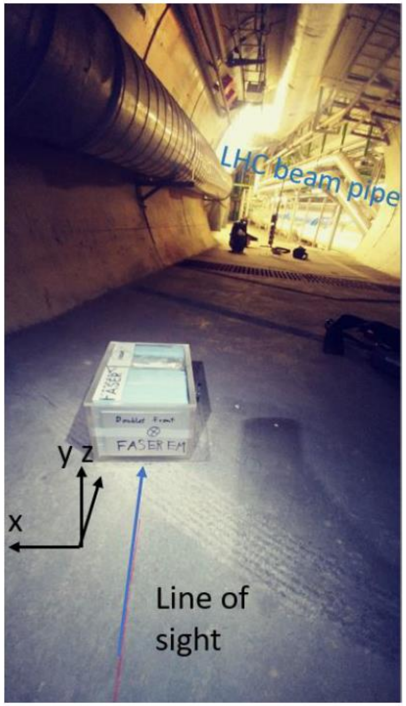




Beam background & Radiation

Beam background

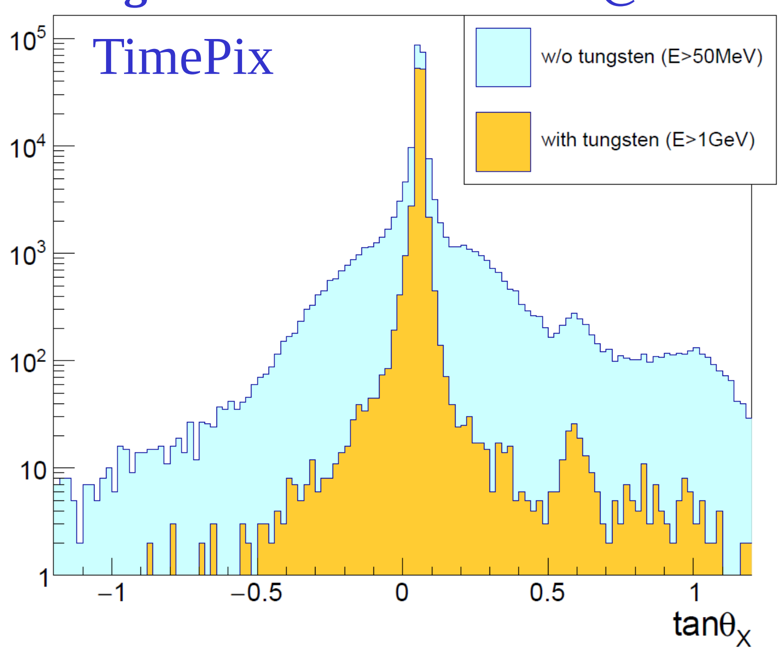
- The emulsion detector and TimePix beam loss monitor were installed at TI12 in 2018 to measure particle flux.
- The results were consistent with FLUKA expectation.
- Detailed study is ongoing.



Radiation

- FLUKA expectation was confirmed by measurement with BatMon detector:
  - $<5 \times 10^{-3}$ Gy/year
  - $<5 \times 10^{7}$ 1 MeV n_{eq}/year
- FASER does not need radiation hard electronics.

Angular dist. of beam BG @TI12

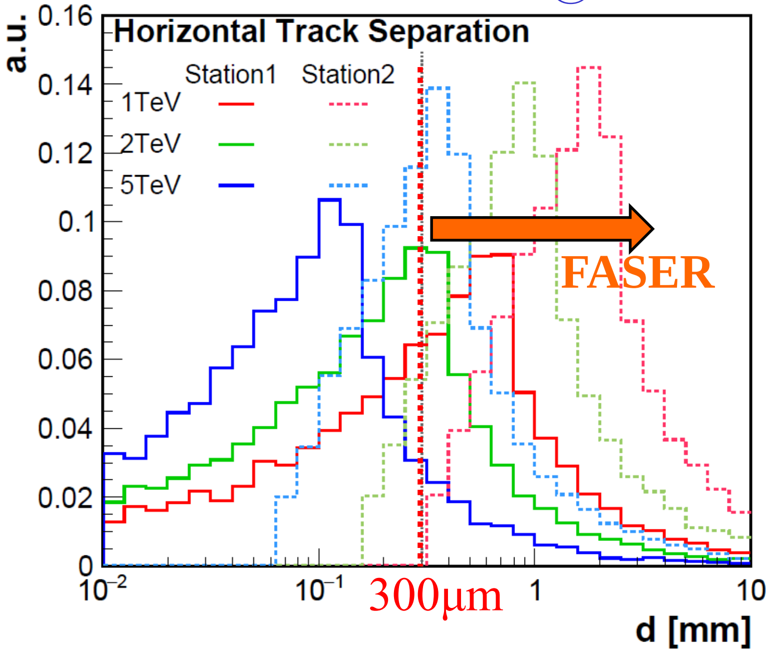


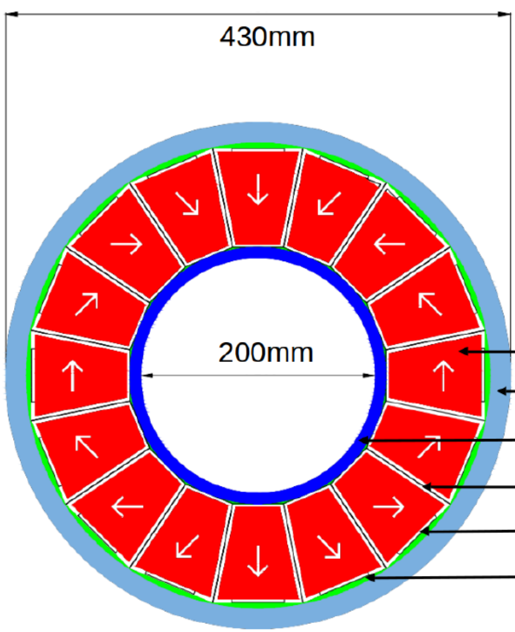
Requirement to spectrometer

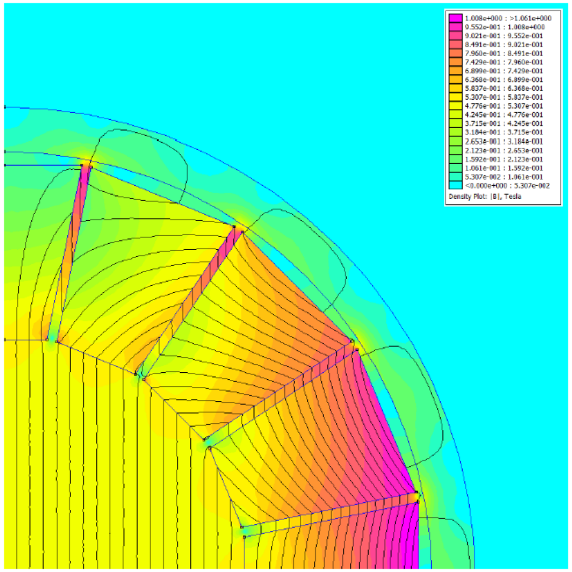
- Permanent magnet with ~0.5 T will be used for e^+e^- separation.
  - ➢ The magnet will be constructed by the CERN magnet group.
- The spectrometer needs to identify two tracks from $A' \rightarrow e^+e^-$ with >300 μm distance (mA' = 100 MeV).

➡ Silicon strip detector will be used for the tracker.

Distance of e^+e^- from A' @FASER

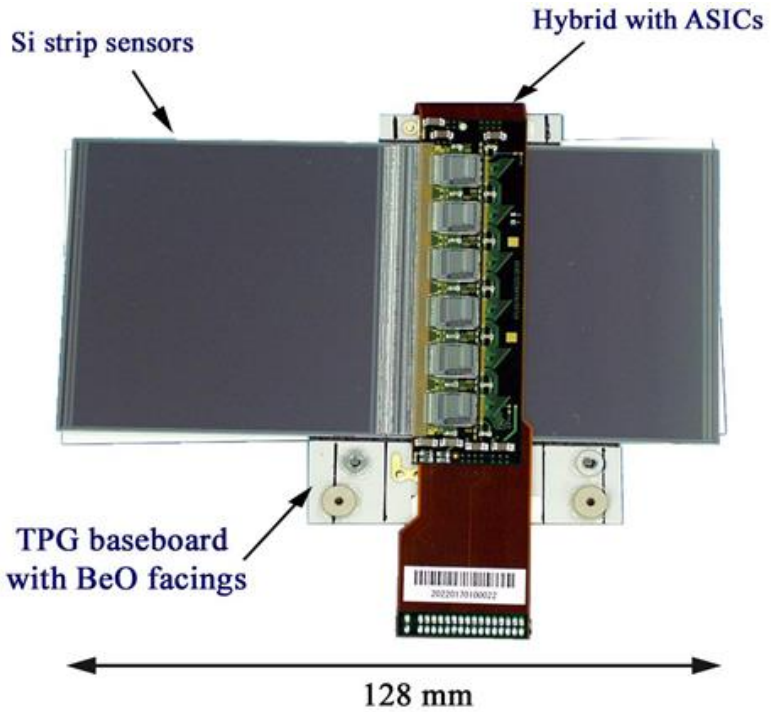


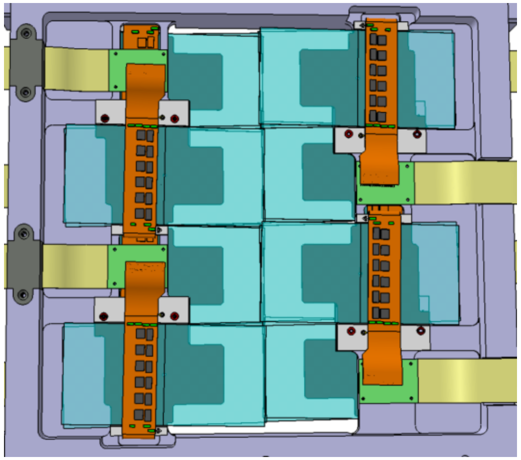


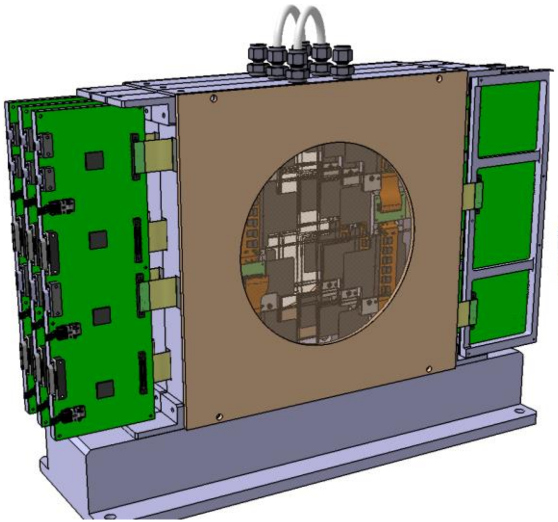


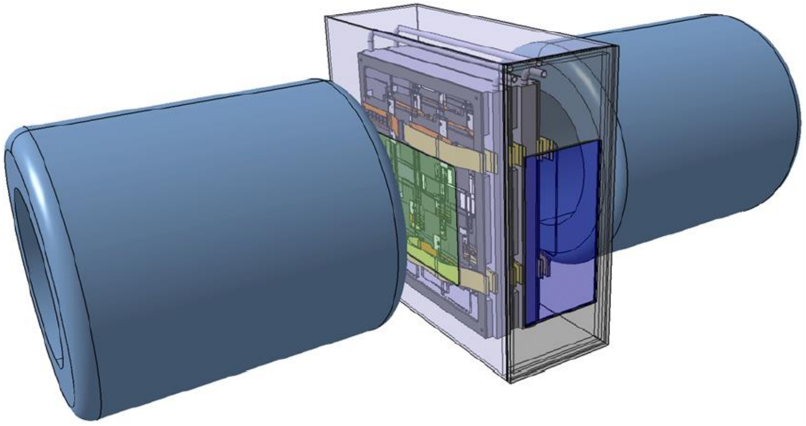
FASER tracker (1)

- 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 with 3 SCT layers.
  - One layer consists of 8 SCT modules.



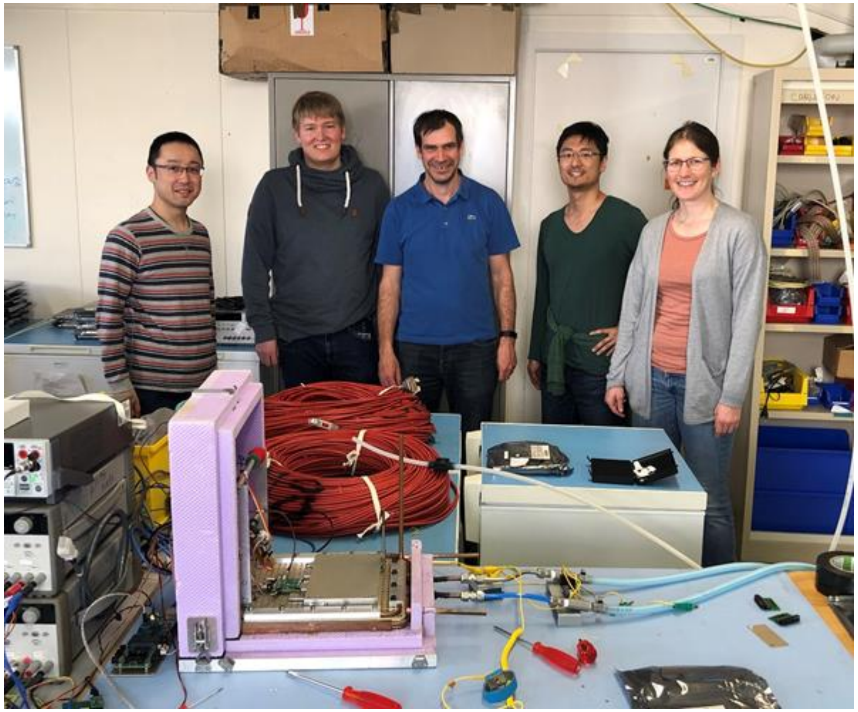




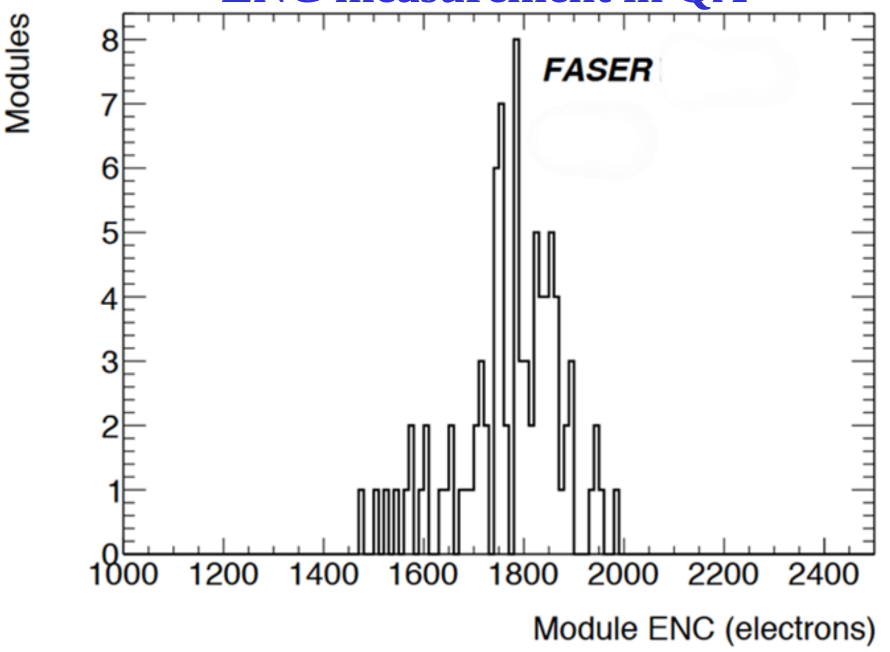


FASER tracker (2)

- Quality assurance test was performed.
  - IV of a sensor
  - ENC (Equivalent Noise charge)
  - # of dead, noisy, cross-talk strips
- Cambridge DAQ system was used for this test with strong support from F. Keizer and S. Wotton.
- 80 modules were already selected for FASER tracker.
- The final design of patch panel, DAQ and support structure is under preparation.



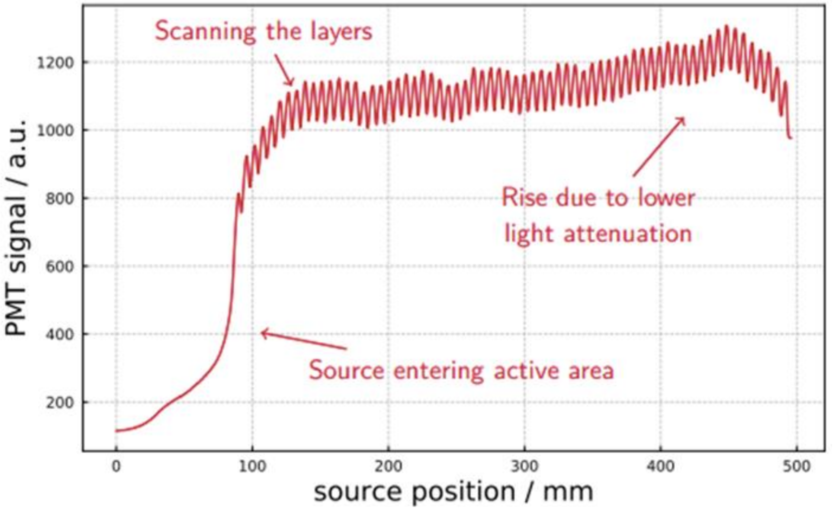
ENC measurement in QA



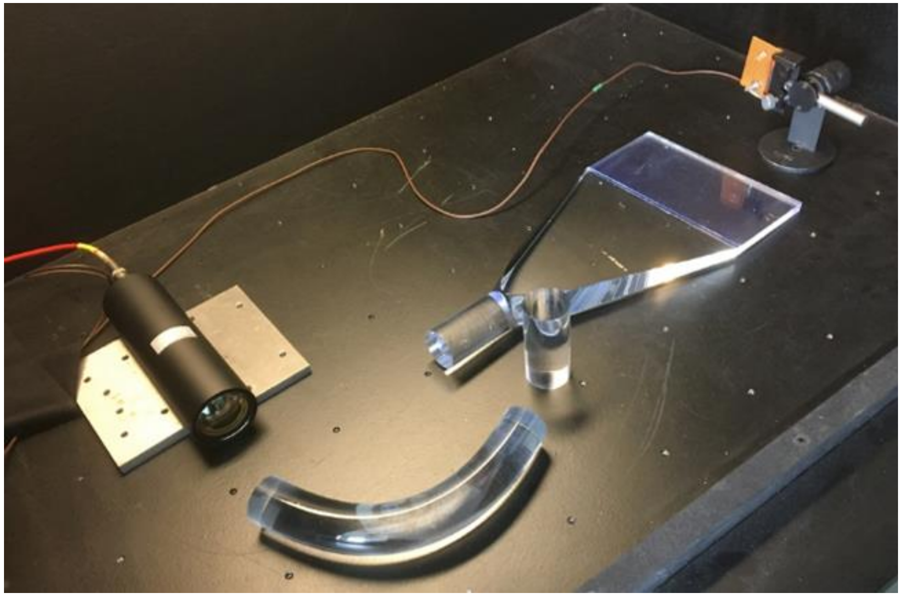
FASER Calorimeter

- FASER calorimeter will be used for measuring EM energy, electron/photon identification and creating 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.
- The performance of the modules was checked already with strong support from Y. Guz!

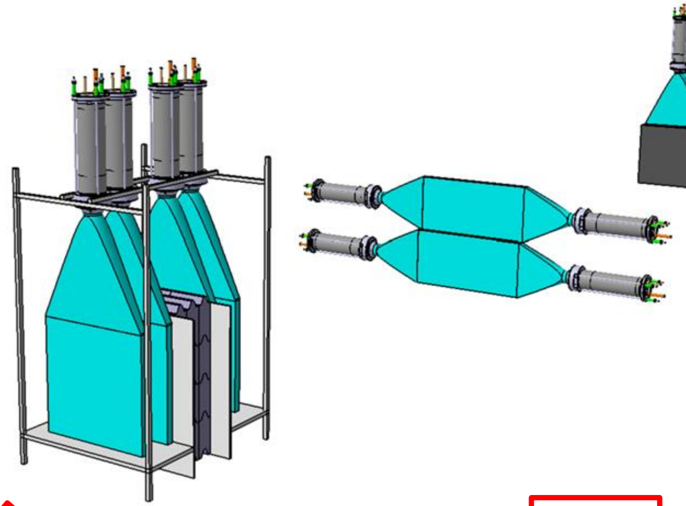
Measurement in FASER QA

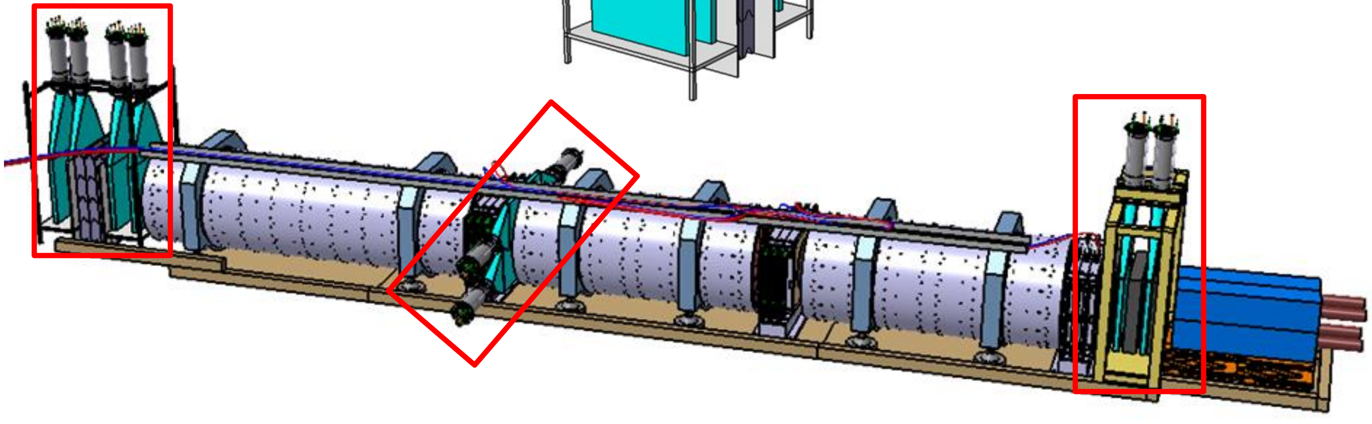


FASER Scintillator



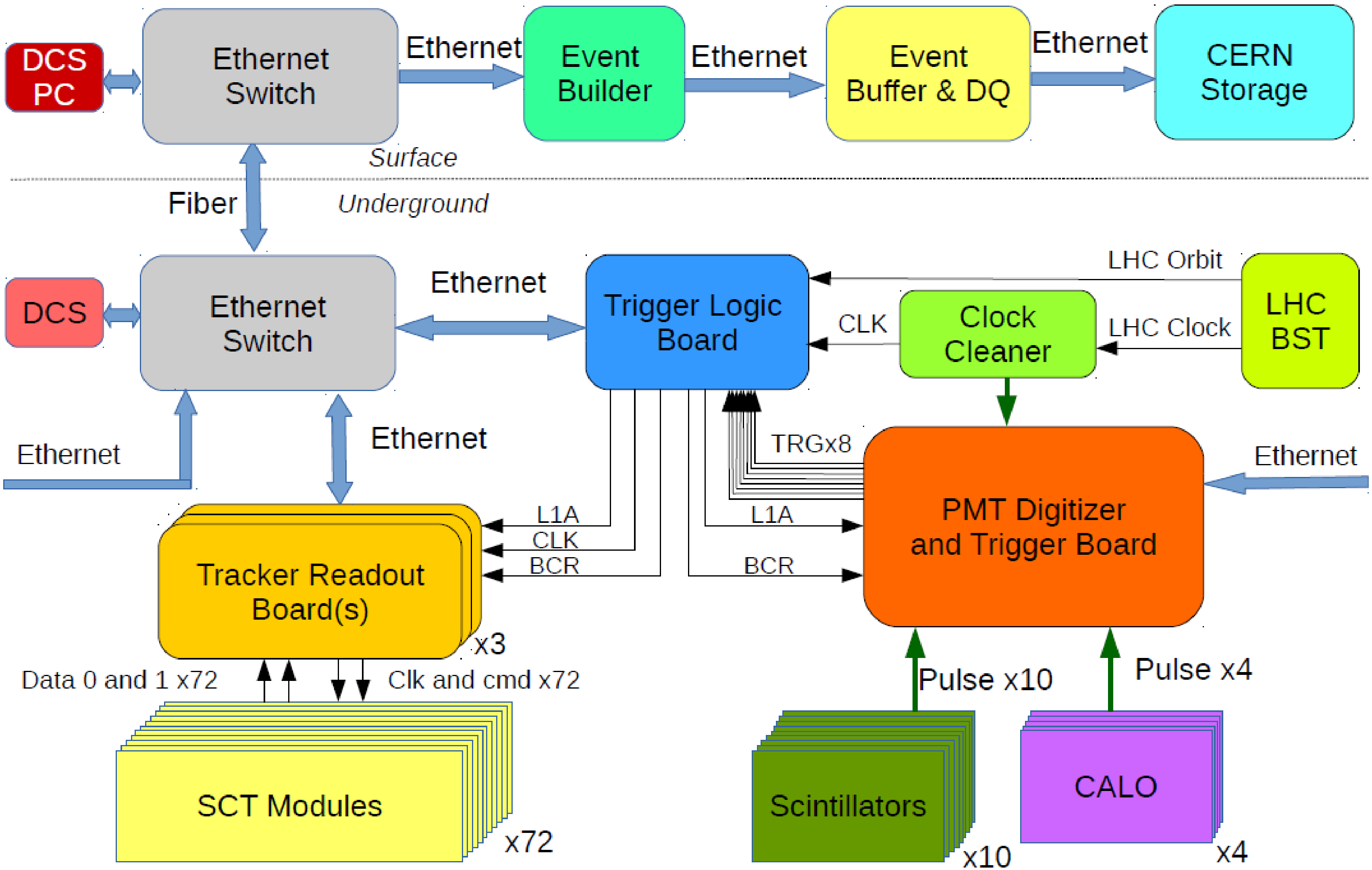
- Scintillator detectors for:
  - Creating a trigger signal.
  - Vetoing charged particles entering the decay volume.
- Require extremely efficient charged particle veto (>99.99%).
  - Important for BG suppression.
- Will be produced at CERN scintillator laboratory.





FASER Trigger/DAQ

TDAQ system dedicated for FASER will be newly developed.

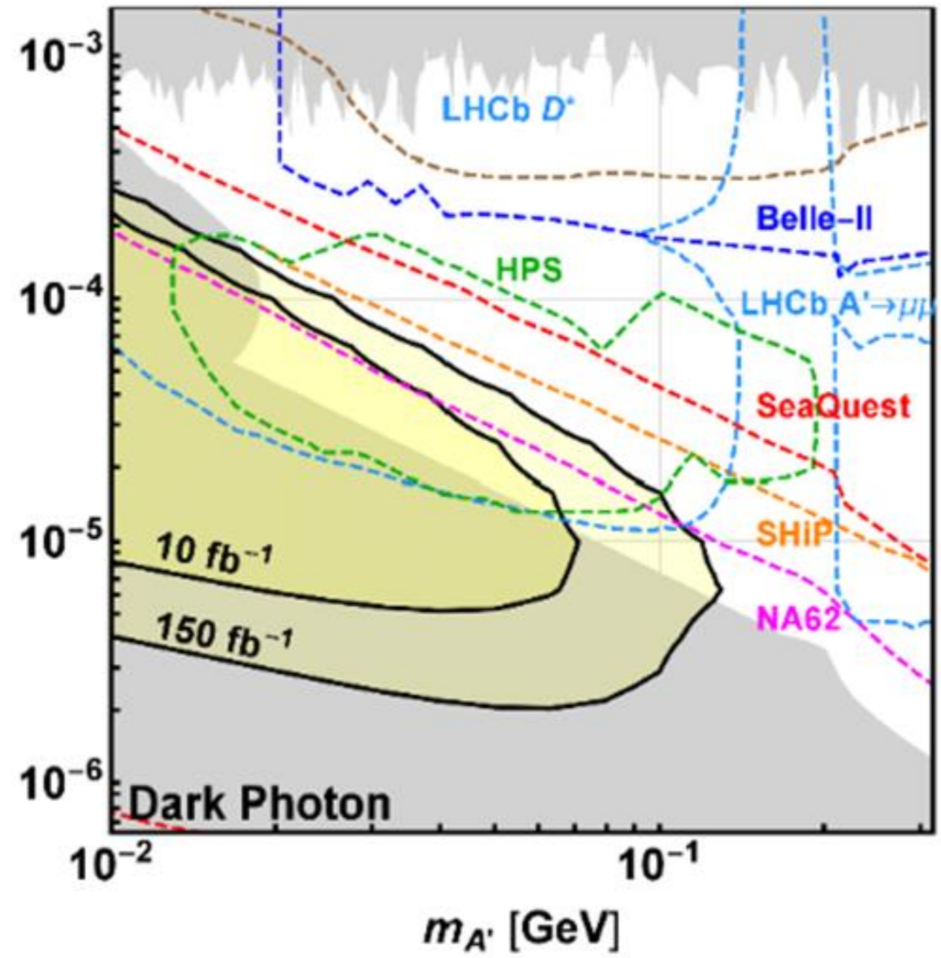


Expected sensitivity to new particles (1)

- The previous experiments gave constraint on weak coupling region.
- FASER has sensitivity to coupling strength of ~10^{-5} for dark photon.
- LHCb and Belle2 will explore strong coupling region.

→ FASER, LHCb and Belle2 are complementary and can cover most search region of $m_{A'} < 1$GeV.

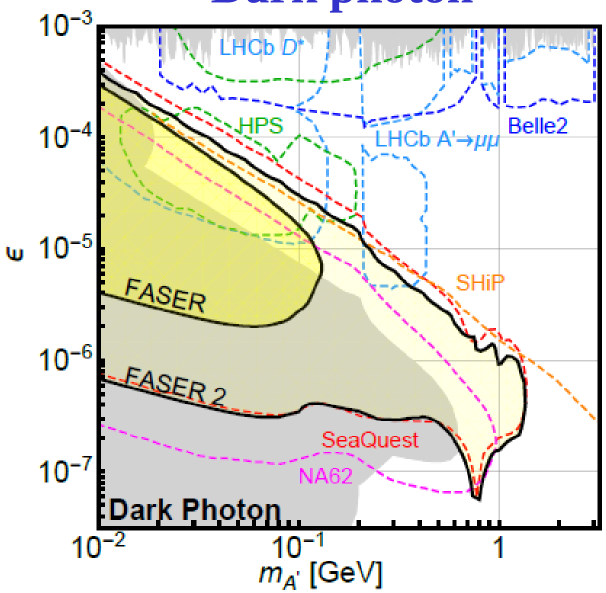
Expected exclusion limits for dark photon



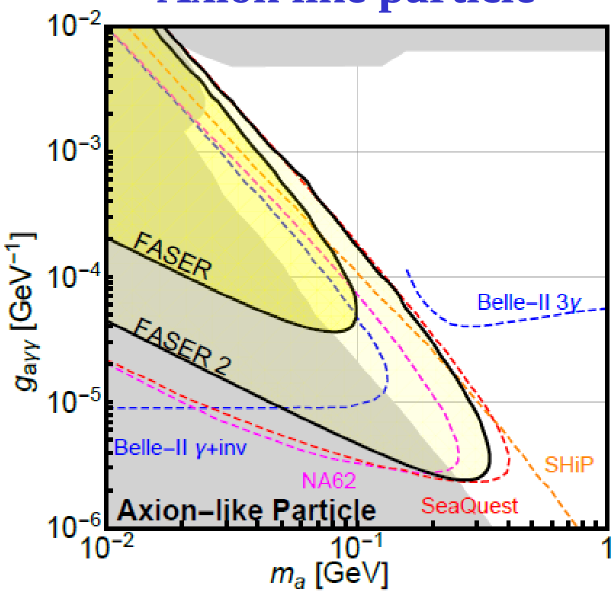
Expected sensitivity to new particles (2)

- FASER2 is a potential upgrade to run in HL-LHC with bigger dimensions of the detector.
  - Radius: 1 m
  - Decay volume length: 5 m
- FASER2 can explore much larger parameter space in dark sectors.

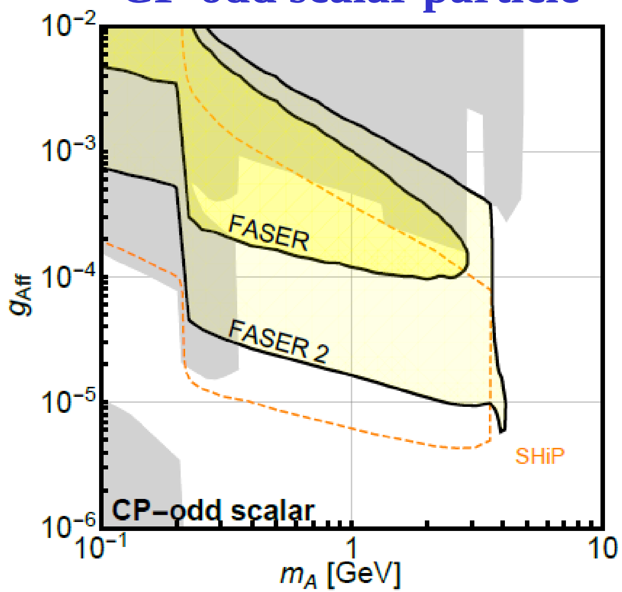
Dark photon



Axion like particle



CP-odd scalar particle



Schedule toward commissioning

- 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 formally approved by CERN at Research Board on March 5th 2019.
- Funding for detector construction/operation was secured from Simons Foundation and Heising-Simons Foundations.
- Construction/Commissioning is planned during LS2.
  - Detector installation is foreseen in ~May 2020.
- Data-taking will start from 2021, synchronizing with LHC Run3.

FASER collaboration

- The FASER Collaboration: 38 collaborators, 16 institutions, 8 countries

Henso Abreu (Technion), Claire Antel (Geneva), Akitaka Ariga (Bern), Tomoko Ariga (Kyushu/Bern), Jamie Boyd (CERN), Dave Casper (UC Irvine), Franck Cadoux (Geneva), Xin Chen (Tsinghua), Andrea Coccaro (INFN), Candan Dozen (Tsinghua), Yannick Favre (Geneva), Jonathan Feng (UC Irvine), Didier Ferrere (Geneva), Iftah Galon (Rutgers), Sergio Gonzalez-Sevilla (Geneva), Shih-Chieh Hsu (Washington), Zhen Hu (Tsinghua), Peppe Iacobucci (Geneva), Sune Jakobsen (CERN), Roland Jansky (Geneva), Enrique Kajomovitz (Technion), Felix Kling (UC Irvine), Susanne Kuehn (CERN), Lorne Levinson (Weizmann), Josh McFayden (CERN), Sam Meehan (CERN), Friedemann Neuhaus (Mainz), Hidetoshi Otono (Kyushu), Lorenzo Paolozzi (Geneva), Brian Petersen (CERN), Osamu Sato (Nagoya), Matthias Schott (Mainz), Anna Sfyrla (Geneva), Jordan Smolinsky (UC Irvine), Aaron Soffa (UC Irvine), Yosuke Takubo (KEK), Eric Torrence (Oregon), Sebastian Trojanowski (Sheffield), Gang Zhang (Tsinghua)

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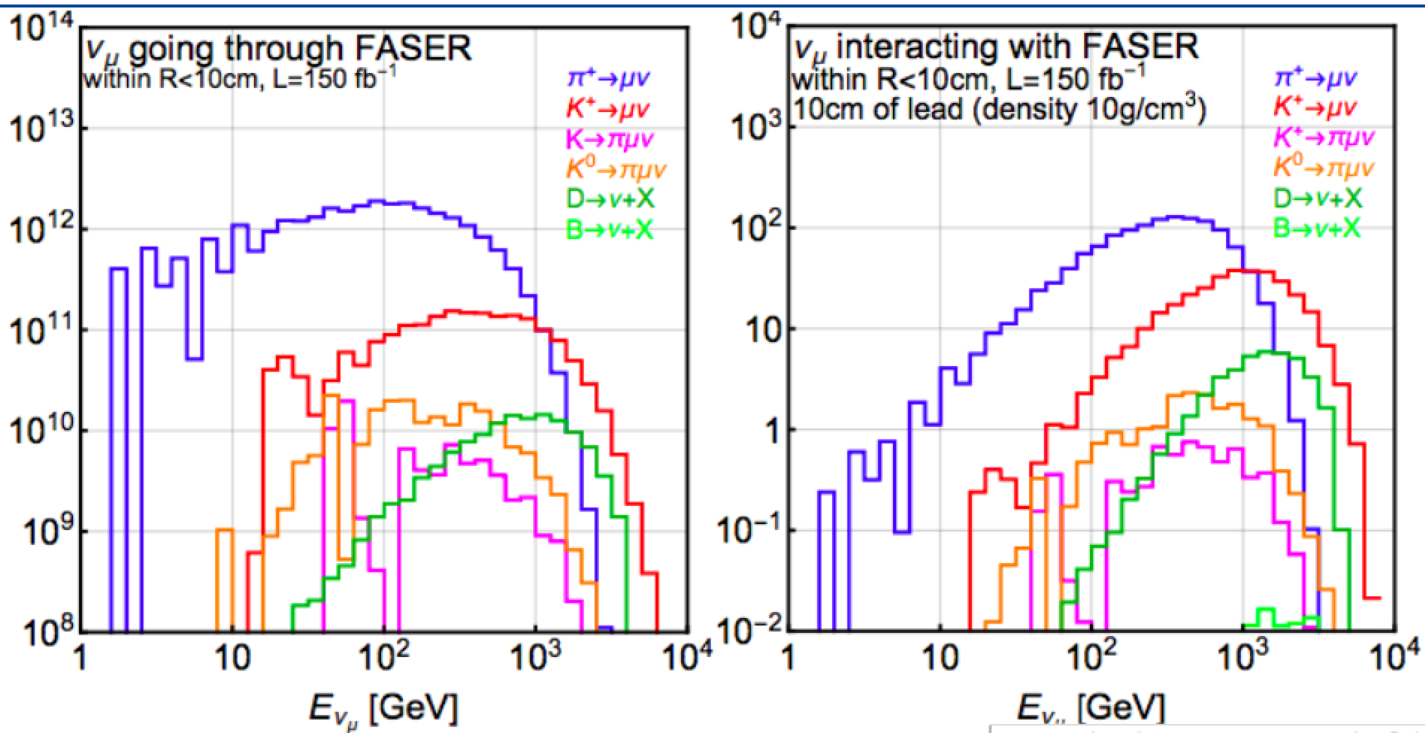
Summary and Conclusions

- FASER will search for new light particles coming from ATLAS pp collision point (IP1).
- The detector will be installed at 480 m away from IP1 where SPS and LHC rings are connected.
- The tracker and calorimeter will use spare modules of ATLAS SCT and LHCb calorimeter, respectively.
- The experiment was approved as CERN project in March 2019 and funded by Simon and Heising-Simon foundations.
- FASER can explore uncovered parameter space of new particle in dark sectors, and is complementary with searches by LHCb and Belle2.
- The detector will be constructed during LS2 and the experiment will start in 2021.
- Many thanks to CERN teams for their support!

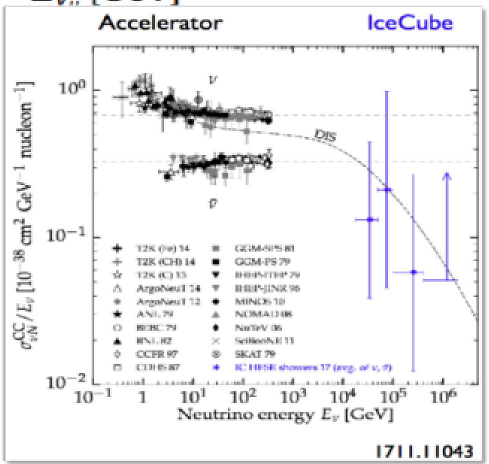
Backup

Possible neutrino measurements (1)



Huge flux of neutrinos through FASER could allow for interesting neutrino measurements e.g. ν_μ CC cross section in unexplored region E>400 GeV.

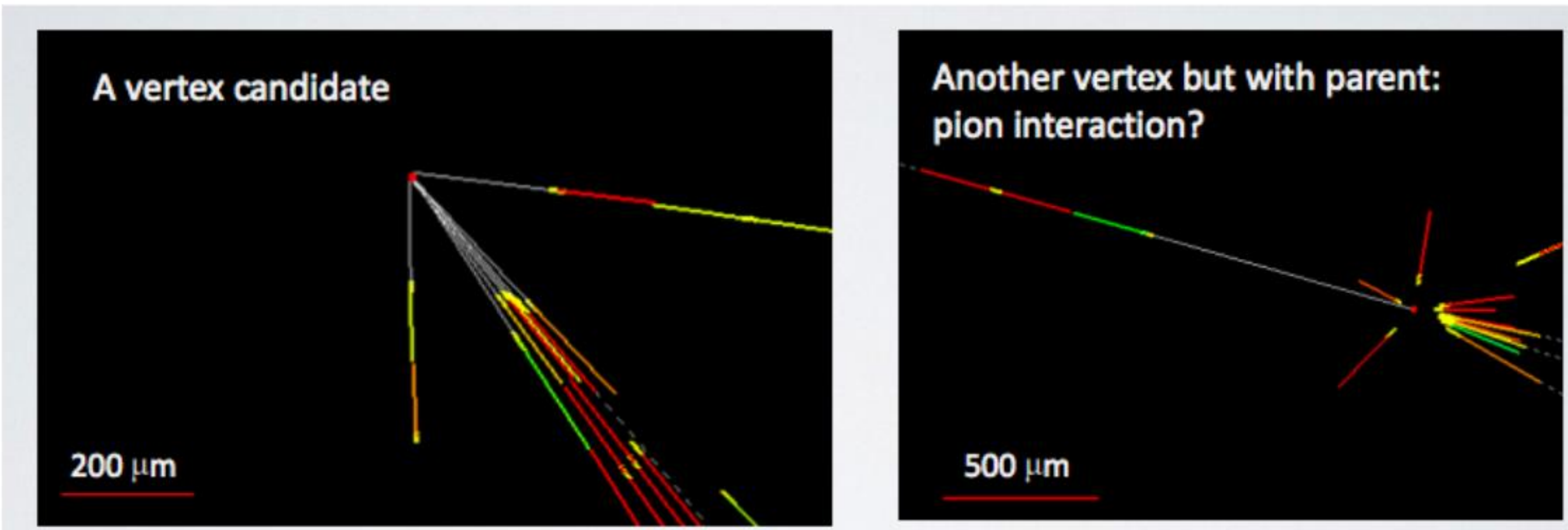
There could also be interesting possibilities for ν_τ measurements at the FASER location (e.g. using emulsion detectors)

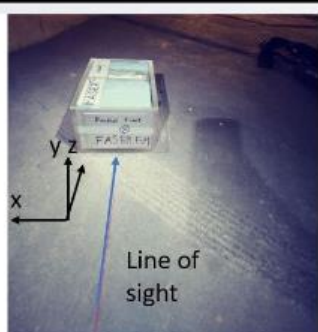


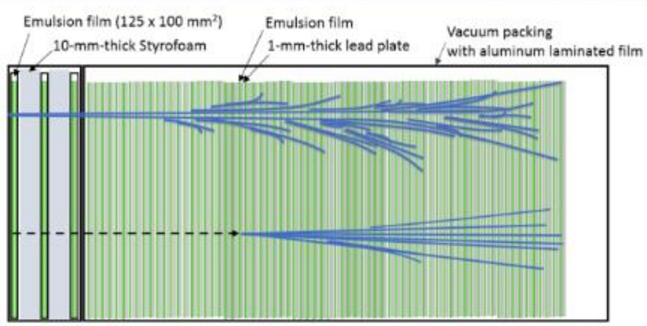
By J. Boid

Possible neutrino measurements (2)

We are already looking for neutrino interactions in the emulsion detectors installed in TI12 in 2018. This corresponded to 30 kg detector for 12.8/fb of data.
First analysis has identified a few multi-track vertices. Further analysis needed to distinguish neutron interactions from neutrino interactions – expect a handful of muon neutrino interactions in this data.







By J. Boid

Dark photon limit

arXiv:1805.06876