FASER experiment

Hidetoshi Otono (Kyushu University)
on behalf of FASER collaboration

KYUSHU UNIVERSITY

10 July, 2019

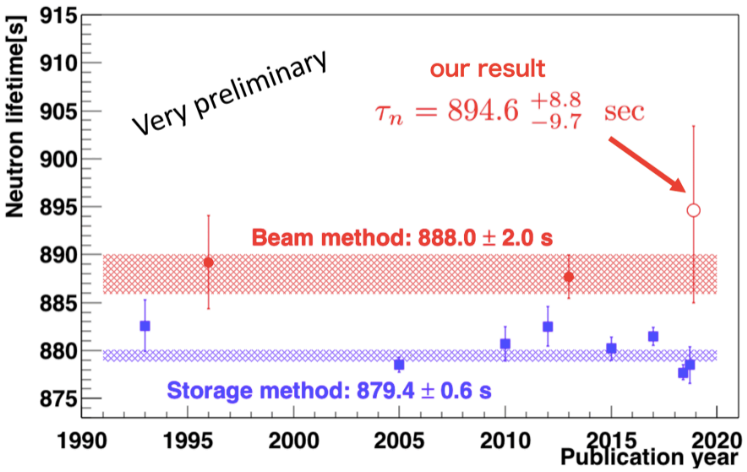
Introduction of myself

Master course:

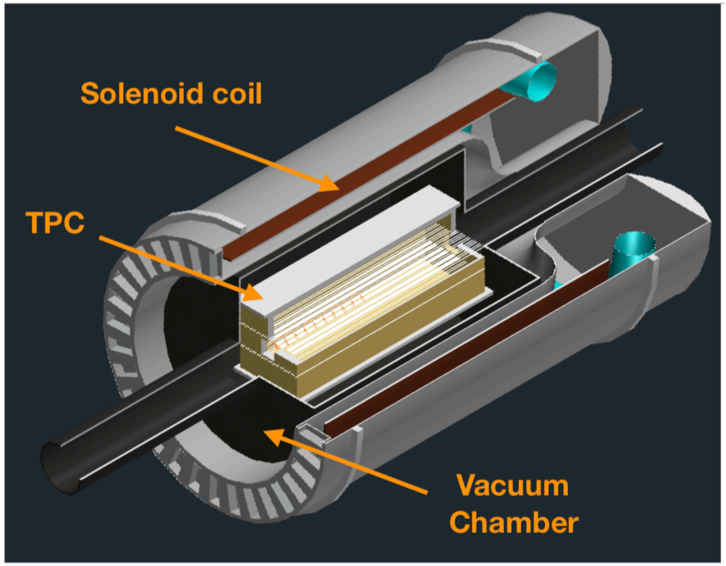
- Development of Geiger-mode silicon photon counter called MPPC or SiPM especially for properties at 77K.

Doctor course:

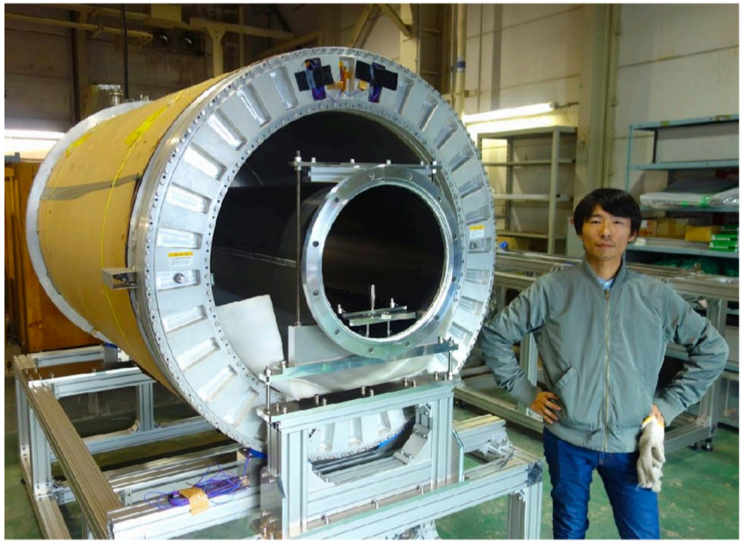
- Development of TPC for neutron lifetime measurement at J-PARC.



LiNA experiment since 2016



https://doi.org/10.1016/j.nima.2016.05.042



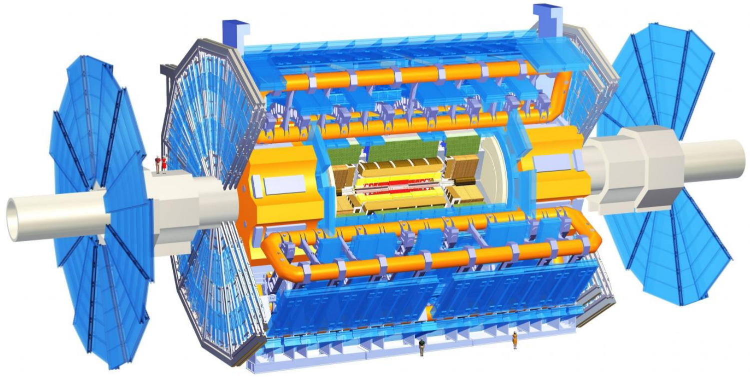
A new idea for neutron lifetime:

- TPC with superconducting magnet to reduce gas-induced background.
  - Spare magnet for BESS (balloon experiment around 2000)

Commissioning in KEK now

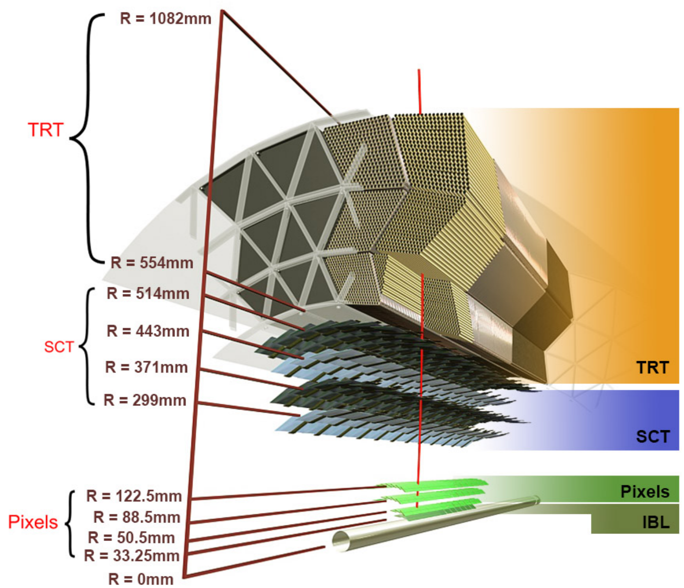
- Aiming to bring to J-PARC in this autumn for the first beam

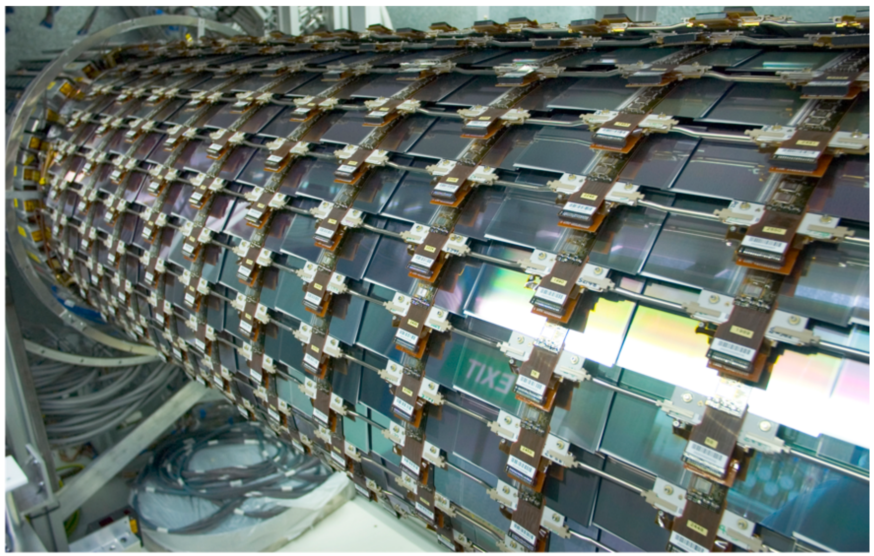
ATLAS experiment since 2013



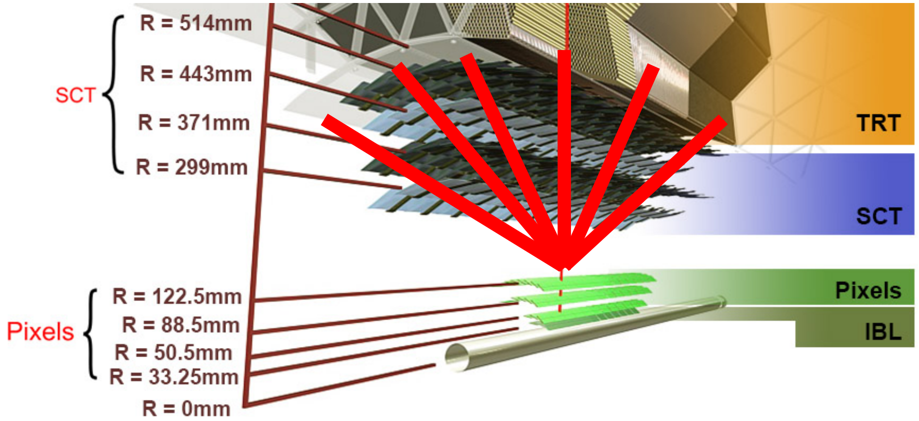
Operation of silicon strip detector (SCT)

- ~99.9% DAQ/DQ efficiency throughout Run2 (2015-2018)
  - Two times higher instantaneous luminosity
- Data taken has been served for all physics analysis
  - Higgs, new particle search, standard model…





ATLAS experiment since 2013

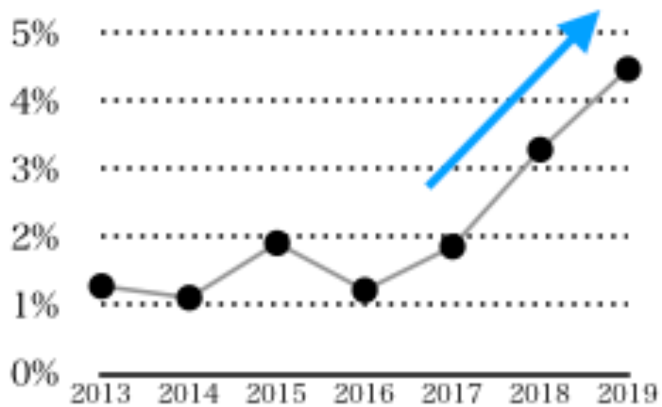


Search for long-lived new particles making displaced vertex

- Run1 full data : the first search using MET trigger - [1504.05162]
- Run2 2016 data : the first search targeting compressed region - [1710.04901]
  - Based on work with Satoshi and Natsumi for co-annilation - 1504.00504 and 1506.08206
  - Have prepared more ideas to exploit full potential of LHC - 1703.09675 and so on

Not so much people were interested in long-lived partilce, but getting popular nowadays:

- Organize annual workshop in Japan
  - http://www.hep.phys.titech.ac.jp/atlas/llp2017/
  - http://www.hep.phys.titech.ac.jp/atlas/llp2018/
- Being prepared for 2019 now



Created by Hide Oide

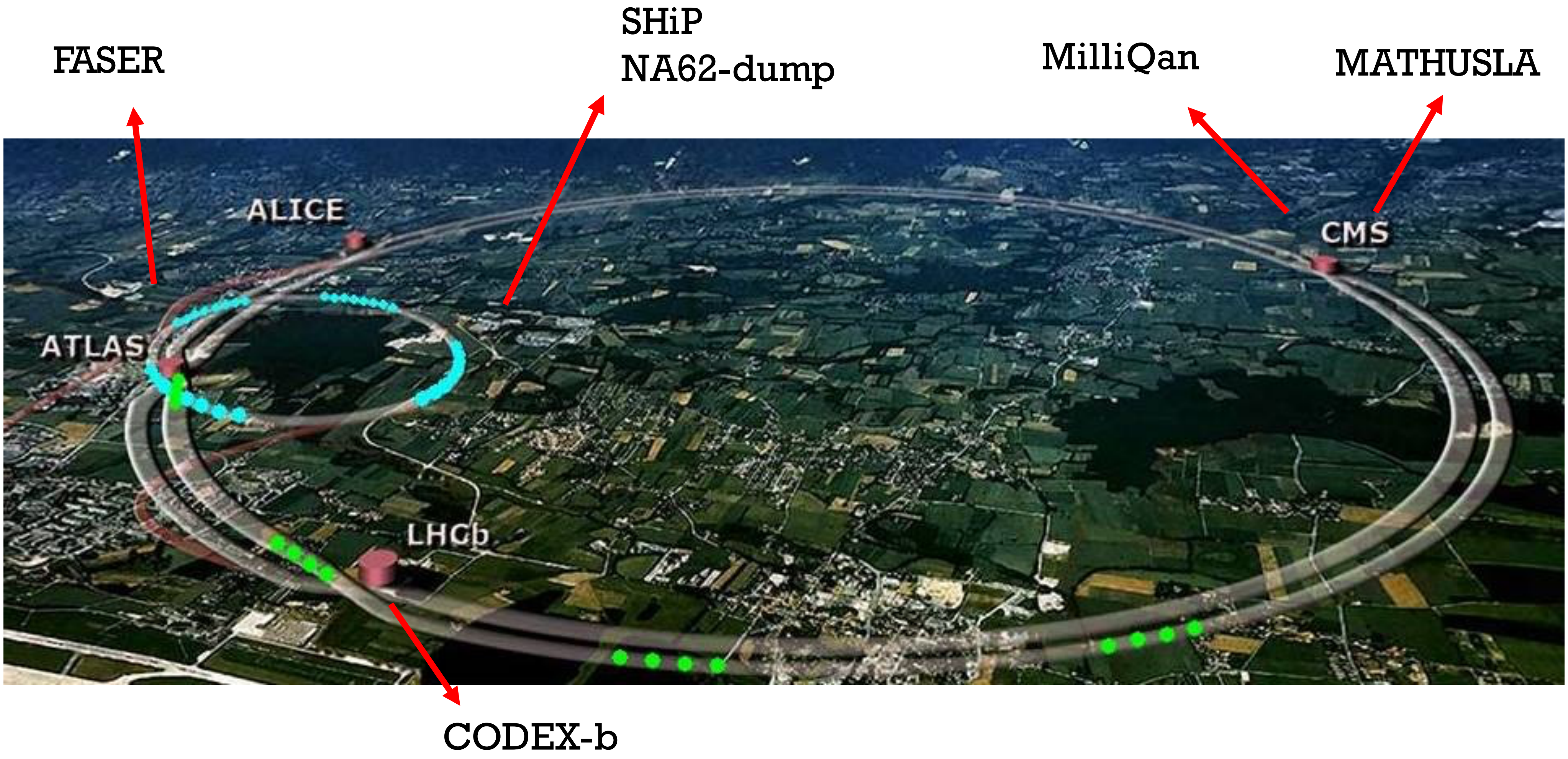
Fraction of article in arXiv including "long-lived" and "LHC"

After Higgs discovery…

No significant new physics from LHC yet,
despite of short comings in SM, e.g.,

- Neutrino masses
- Dark matter
- Baryon Asymmetry of Universe

Examples of recently proposed experiments in CERN



Every experiment keeps (or boosts) momentum to get started ASAP !

New light particle ?

At the LHC, new physics searches focus on high p_T.

- Best approach for **heavy**, **strongly** interacting particles.

However, if new particles are **light** and **weakly** interacting, this may be completely misguided.

- Long-lived particle would be produced.

FASER is a proposed experiment designed to cover this scenario at the LHC.

Getting started from ~2018

FASER: ForwArd Search ExpeRiment at the LHC

Jonathan L. Feng, Iftah Galon, Felix Kling, Sebastian Trojanowski

(Submitted on 30 Aug 2017 (v1), last revised 14 Jun 2018 (this version, v3))

arXiv:1708.09389

↓

LoI submitted to LHCC on Jun 18th

Letter of Intent for FASER: ForwArd Search ExpeRiment at the LHC

FASER Collaboration, Akitaka Ariga, Tomoko Ariga, Jamie Boyd, David W. Casper, Jonathan L. Feng, Iftah Galon, Shih-Chieh Hsu, Felix Kling, Hidetoshi Otono, Brian Petersen, Osamu Sato, Aaron M. Soffa, Jeffrey R. Swaney, Sebastian Trojanowski

(Submitted on 26 Nov 2018)

arXiv:1811.10243

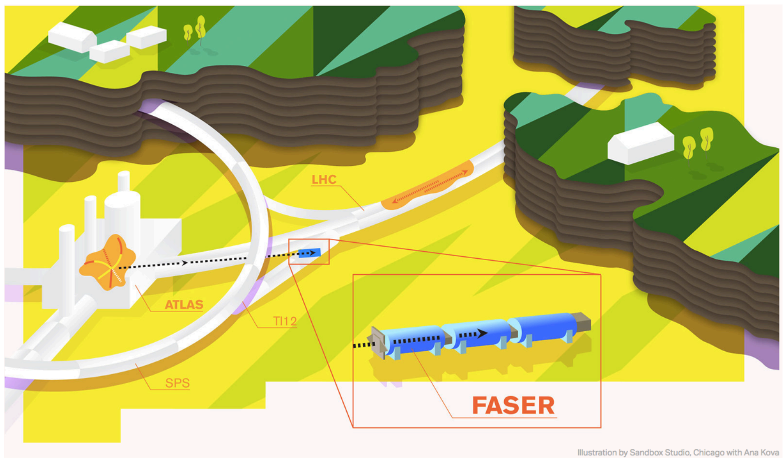
↓

Technical proposal submitted to LHCC on Oct 26th

Approved by CERN on 7th March

FASER: CERN approves new experiment to look for long-lived, exotic particles

The experiment, which will complement existing searches for dark matter at the LHC, will be operational in 2021



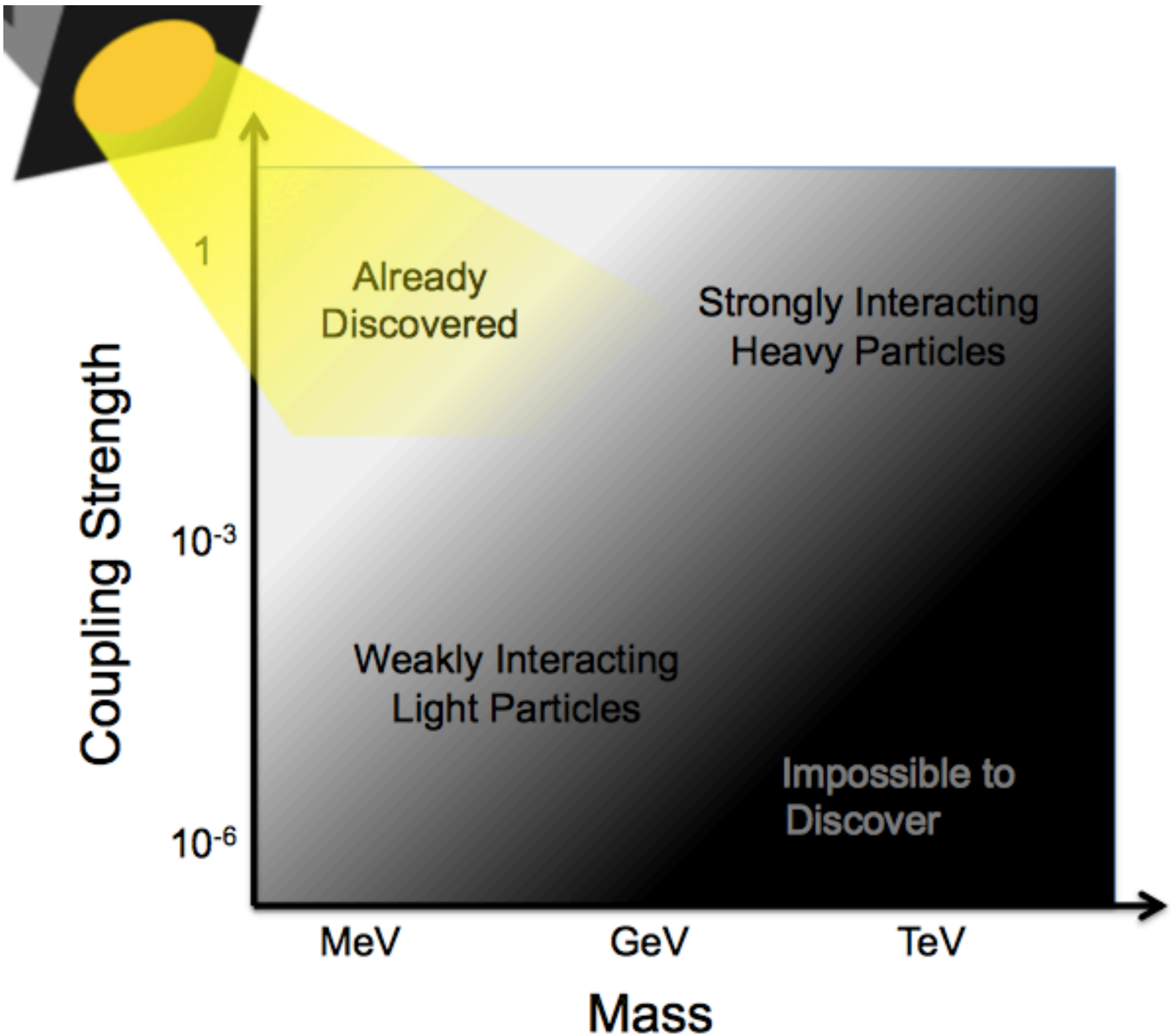
https://www.symmetrymagazine.org/article/a-tiny-new-experiment-at-the-lhc

FASER is founded by the Heising-Simons Foundation and the Simons Foundation.

Current collaboration

The FASER Collaboration: 35 collaborators, 16 institutions, 8 countries

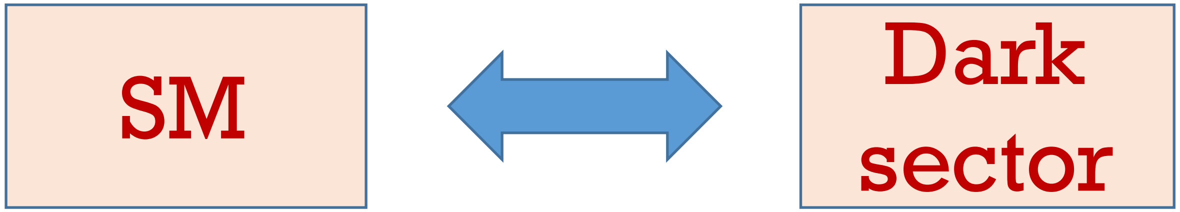
Claire Antel (Geneva), Akitaka Ariga (Bern), Tomoko Ariga (Kyushu/Bern), Jamie Boyd (CERN), Dave Casper (UC Irvine), Franck Cadoux (Geneva), Xin Chen (Tsinghua), Andrea Coccaro (Genova), Candan Dozen (Tsinghua), Yannick Favre (Geneva), Jonathan Feng (UC Irvine), Didier Ferrere (Geneva), Iftah Galon (Rutgers), Sergio Gonzalez-Sevilla (Geneva), Shih-Chieh Hsu (Washington), Zhen Hu (Tsinghua), Peppe Iacobucci (Geneva), Roland Jansky (Geneva), Enrique Kajomovitz (Technion), Felix Kling (UC Irvine), Susanne Kuehn (CERN), Lorne Levinson (Weizmann), Josh McFayden (CERN), Friedemann Neuhaus (Mainz), Hidetoshi Otono (Kyushu), 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)



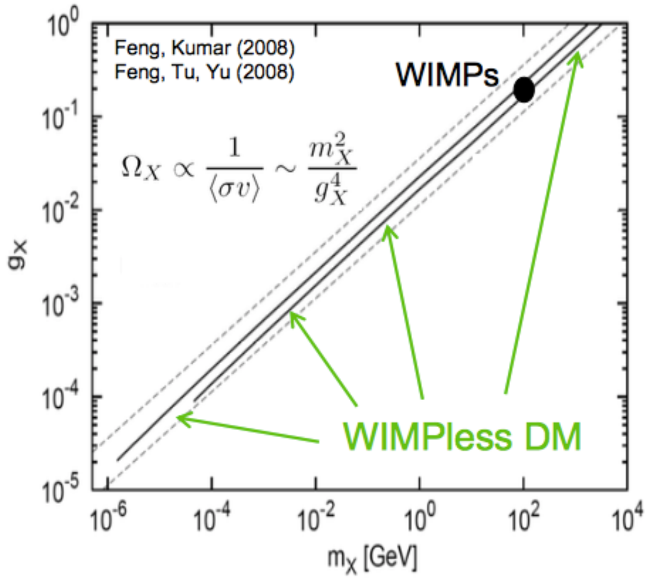
1
Already Discovered
Strongly Interacting Heavy Particles
10-3
Coupling Strength
Weakly Interacting Light Particles
Impossible to Discover
10-6
MeV
GeV
TeV
Mass

Physics : Dark sector

The idea of dark matter has been recently generalized to dark sectors.



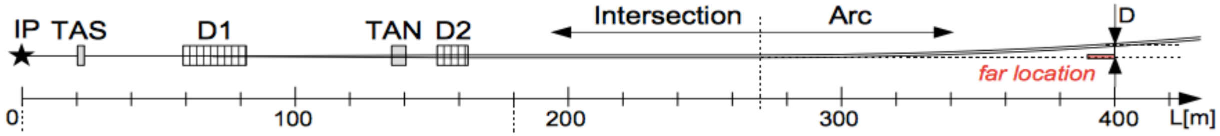
Vector portal
Higgs portal
Neutrino portal
Axion portal
…

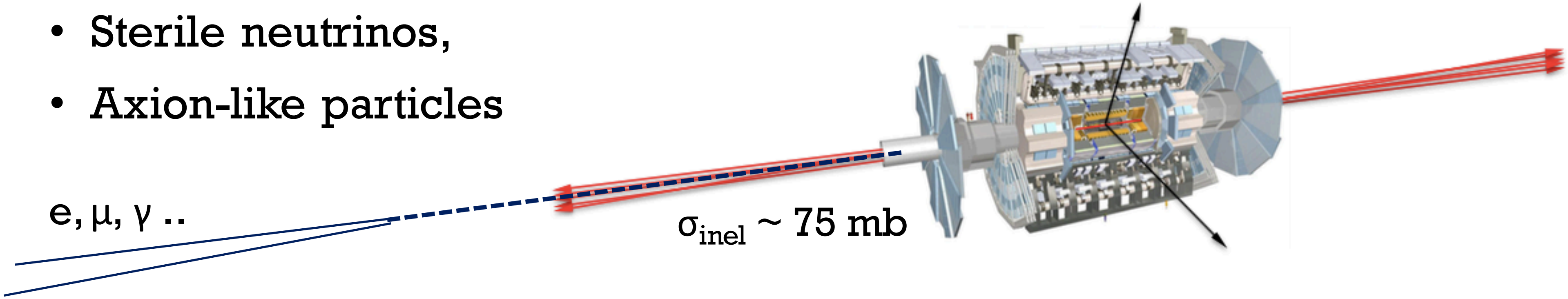


FASER experiment

Search for various long-lived particles produced in the forward direction of ATLAS, *e.g*, in rare meson decay:

- Dark photons,
- Dark Higgs bosons,
- Sterile neutrinos,
- Axion-like particles

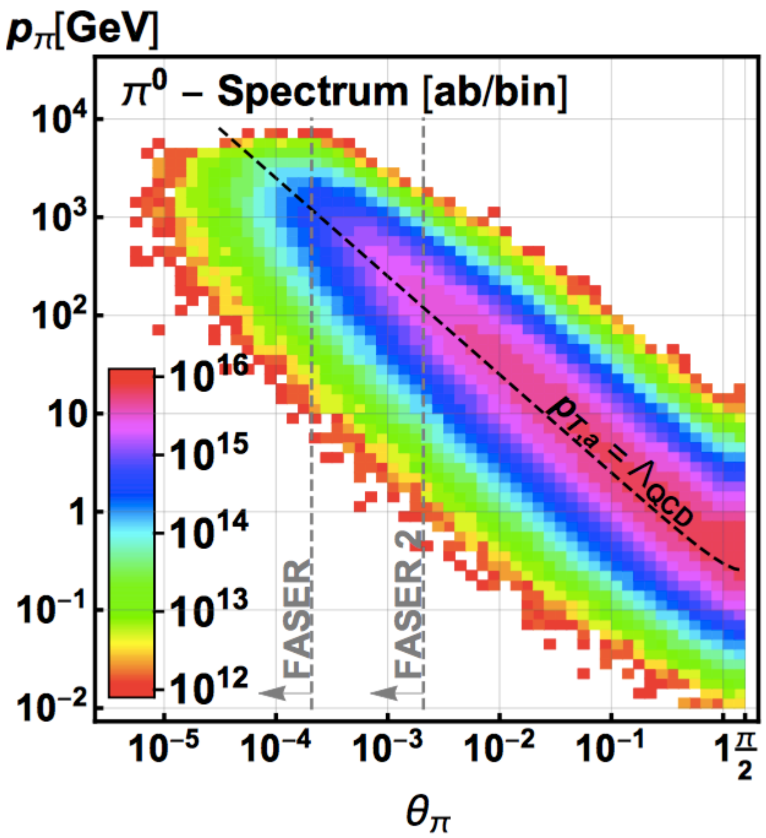


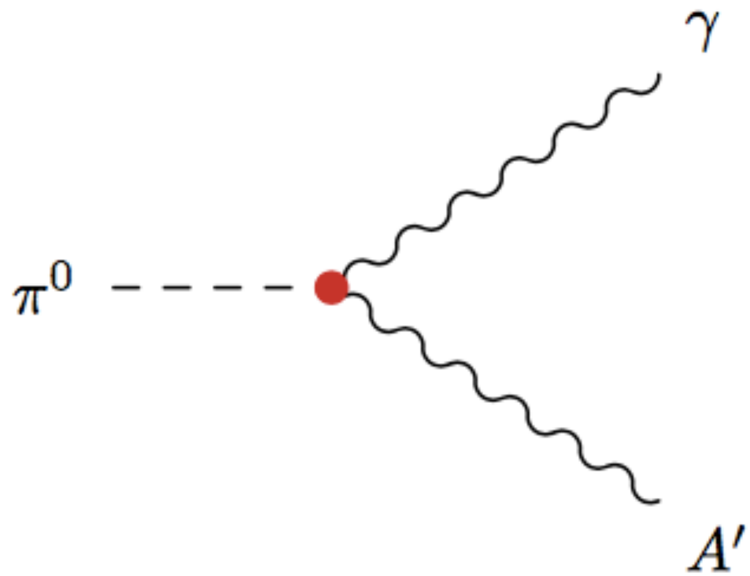


Highly-collimated (mrad ~ Λ_{QCD}/TeV) along the beam axis:

- Even at 400m, ϕ 20 cm detector provides good sensitivity for NP.
- Neutrinos are also arrived.

Dark photon properties





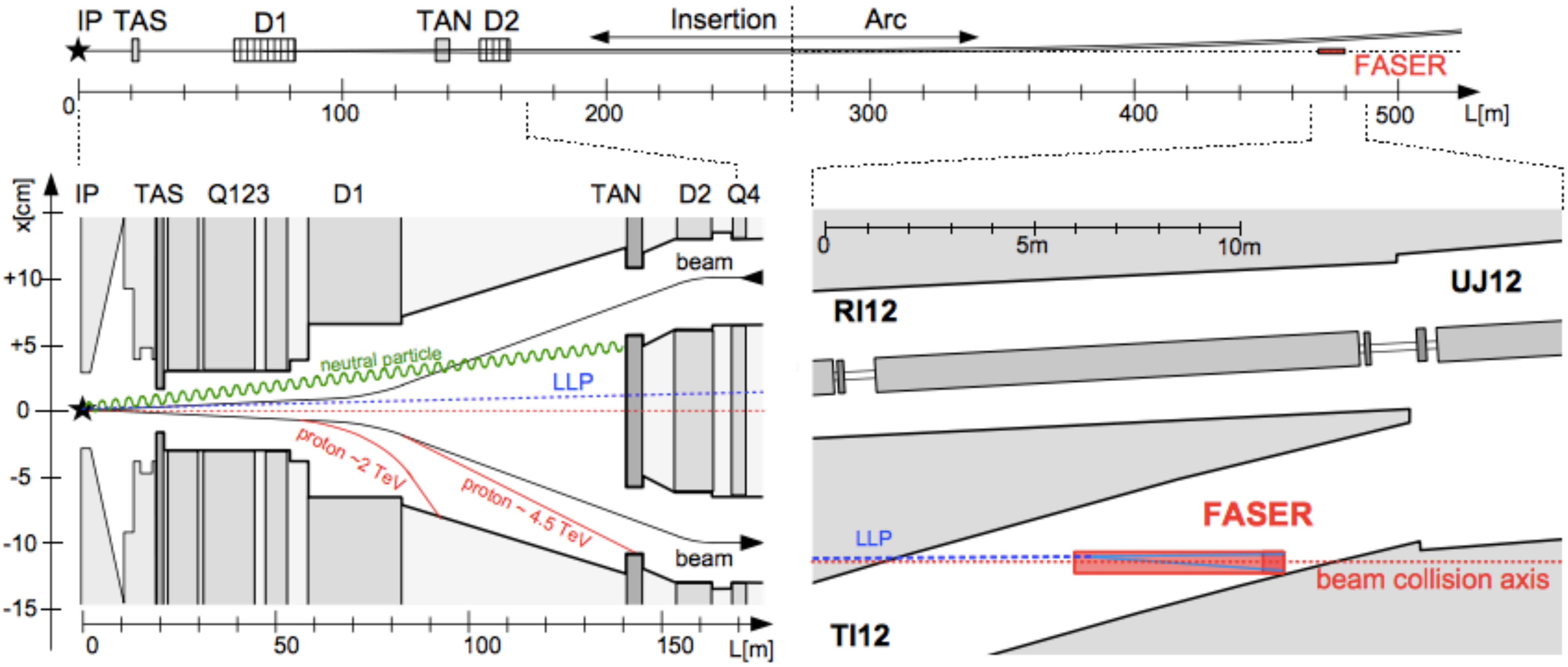
Long lifetime : $\bar{d} = c\,\frac{1}{\Gamma_{A'}}\gamma_{A'}\beta_{A'} \approx (80\ \mathrm{m})\ B_e \left[\frac{10^{-5}}{\epsilon}\right]^2 \left[\frac{E_{A'}}{\mathrm{TeV}}\right]$

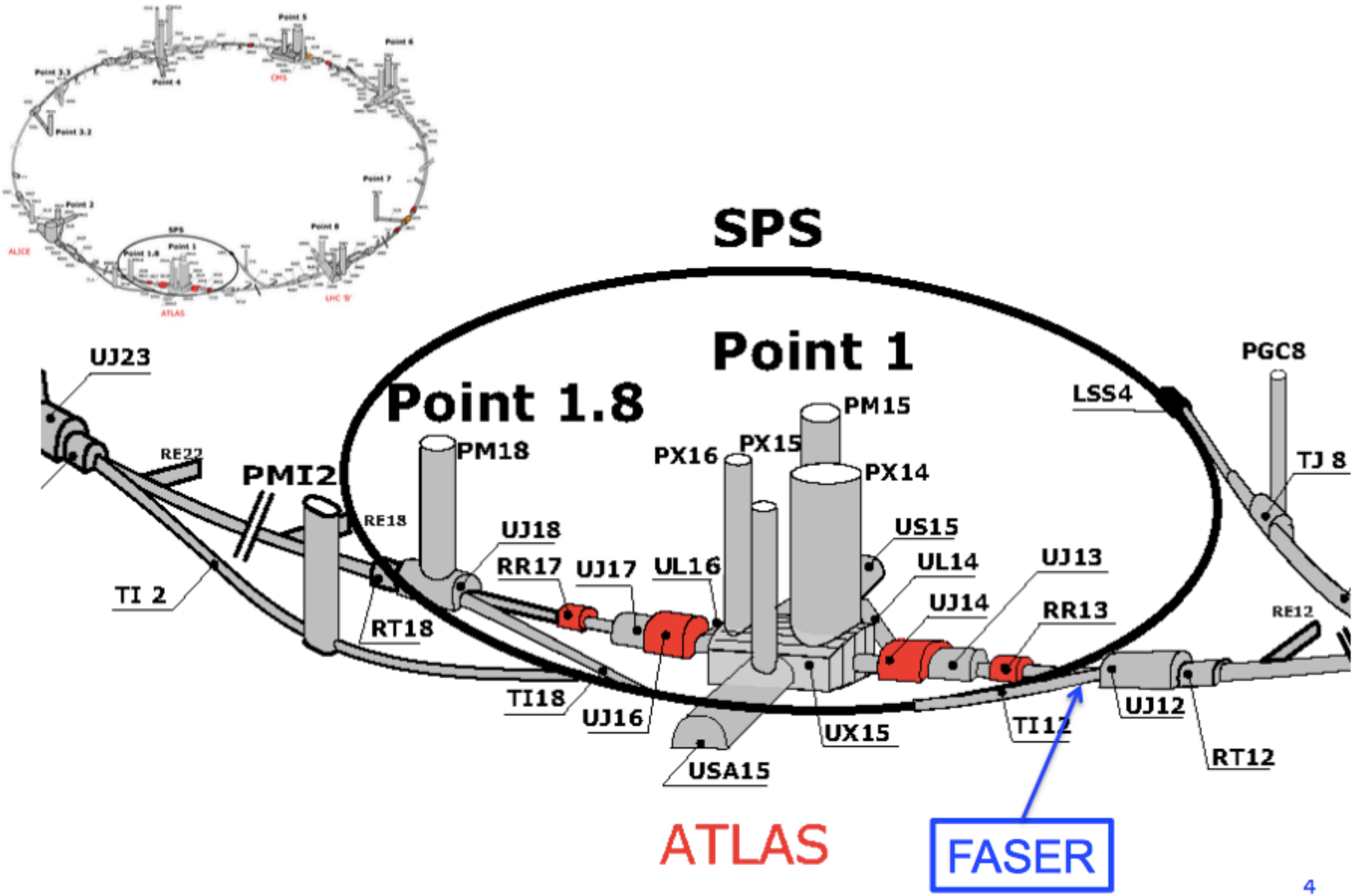
Decay to pair of electron / muon / pion

Location : Service tunnel TI12

FASER should be placed along the beam collision axis.

- TI12 is 400 m away from IP, which has not been used for experiments.




SPS
Point 1
Point 1.8
UJ23
PGC8
LSS4
PM15
PM18
PX16
PX15
PX14
RE22
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RE18
UJ18
US15
TJ 8
UL14
UJ13
RR17
UJ17
UL16
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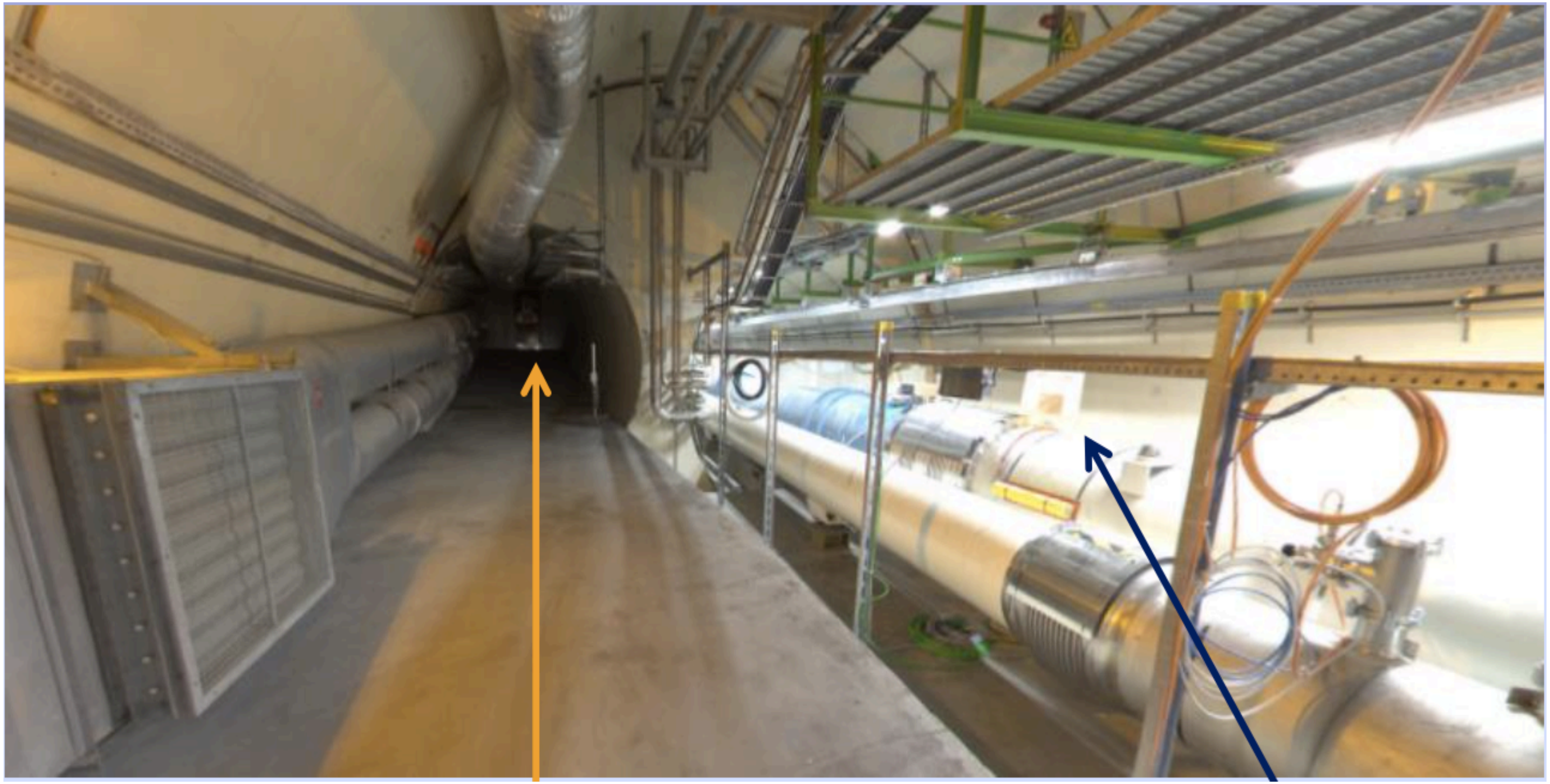
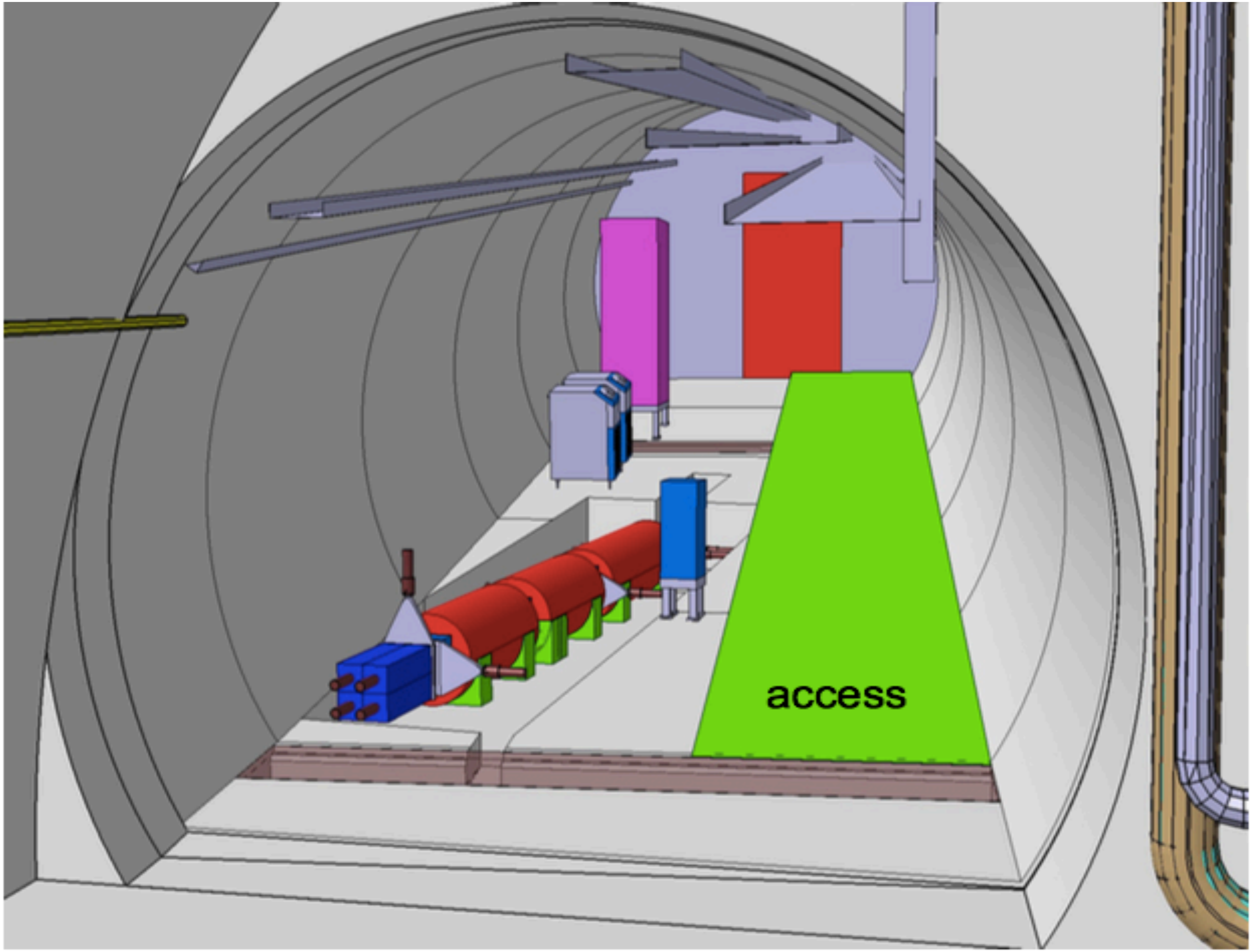
USA15
ATLAS
FASER

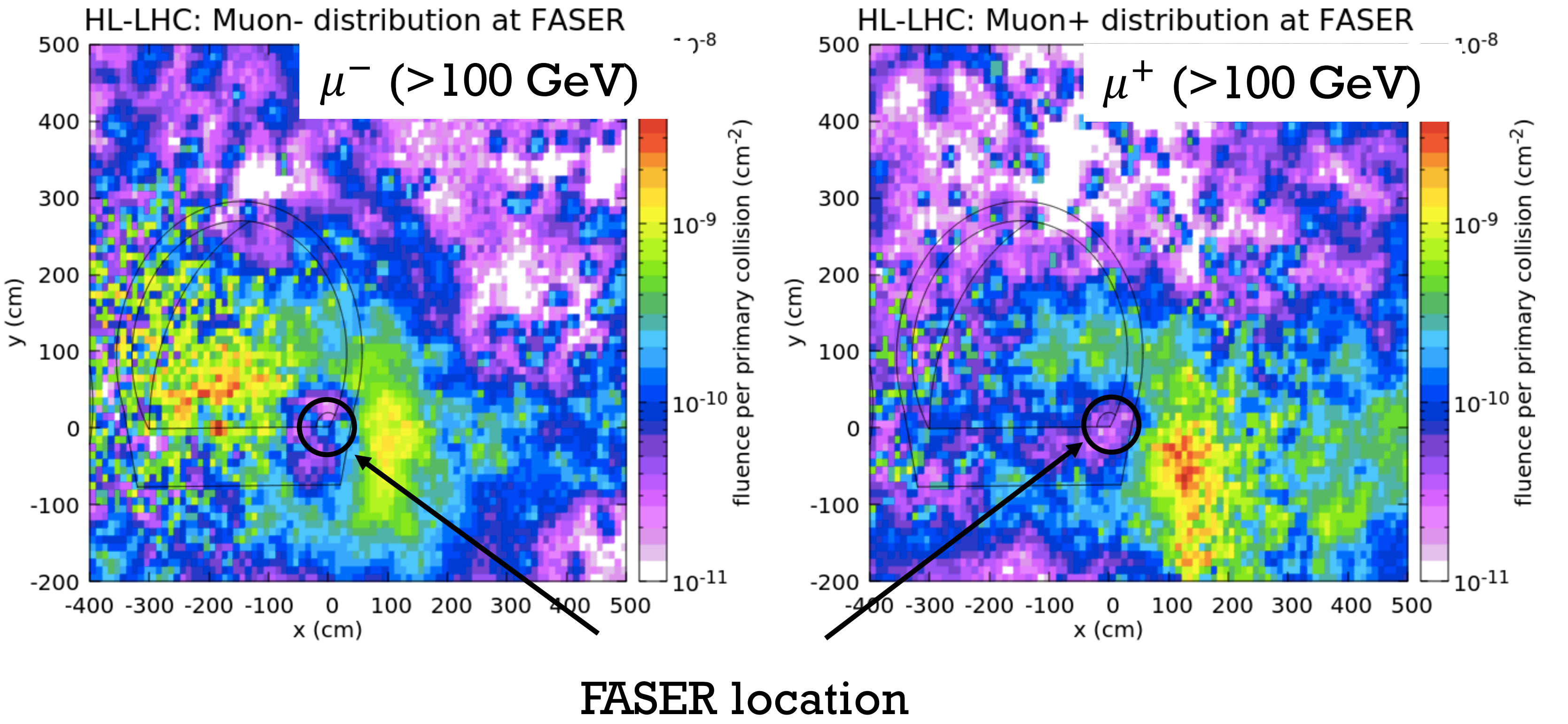


Experimental area – floor will be lowered by ~ 50 cm.

LHC main tunnel


access

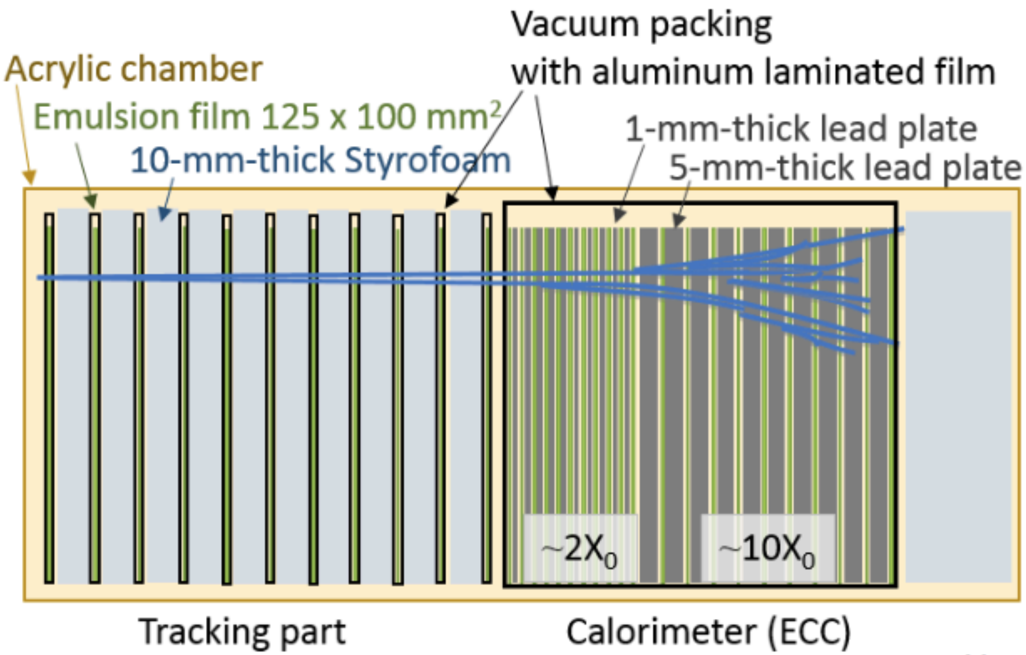
Simulation for background

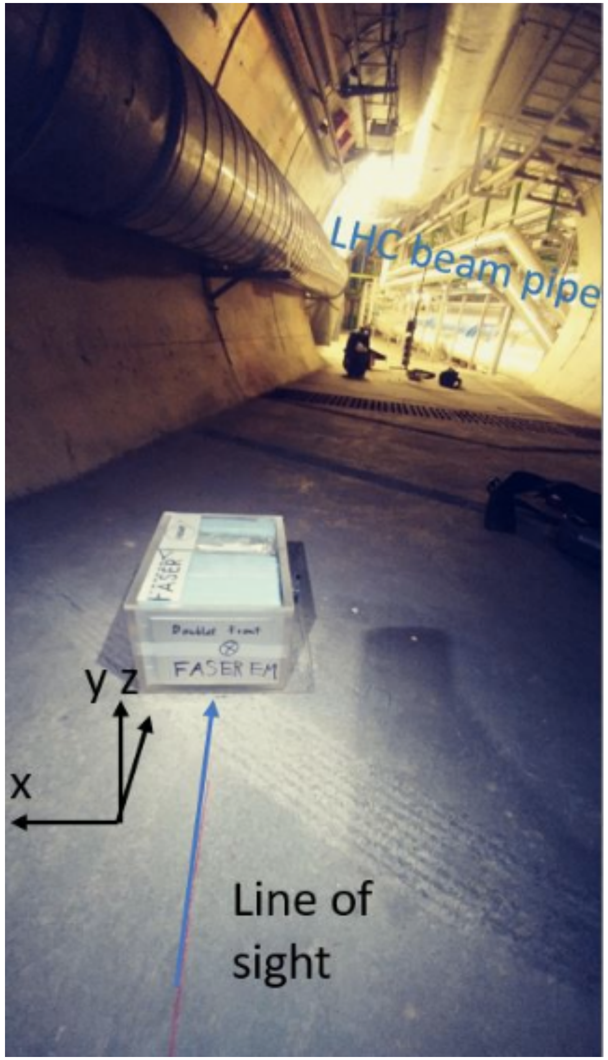


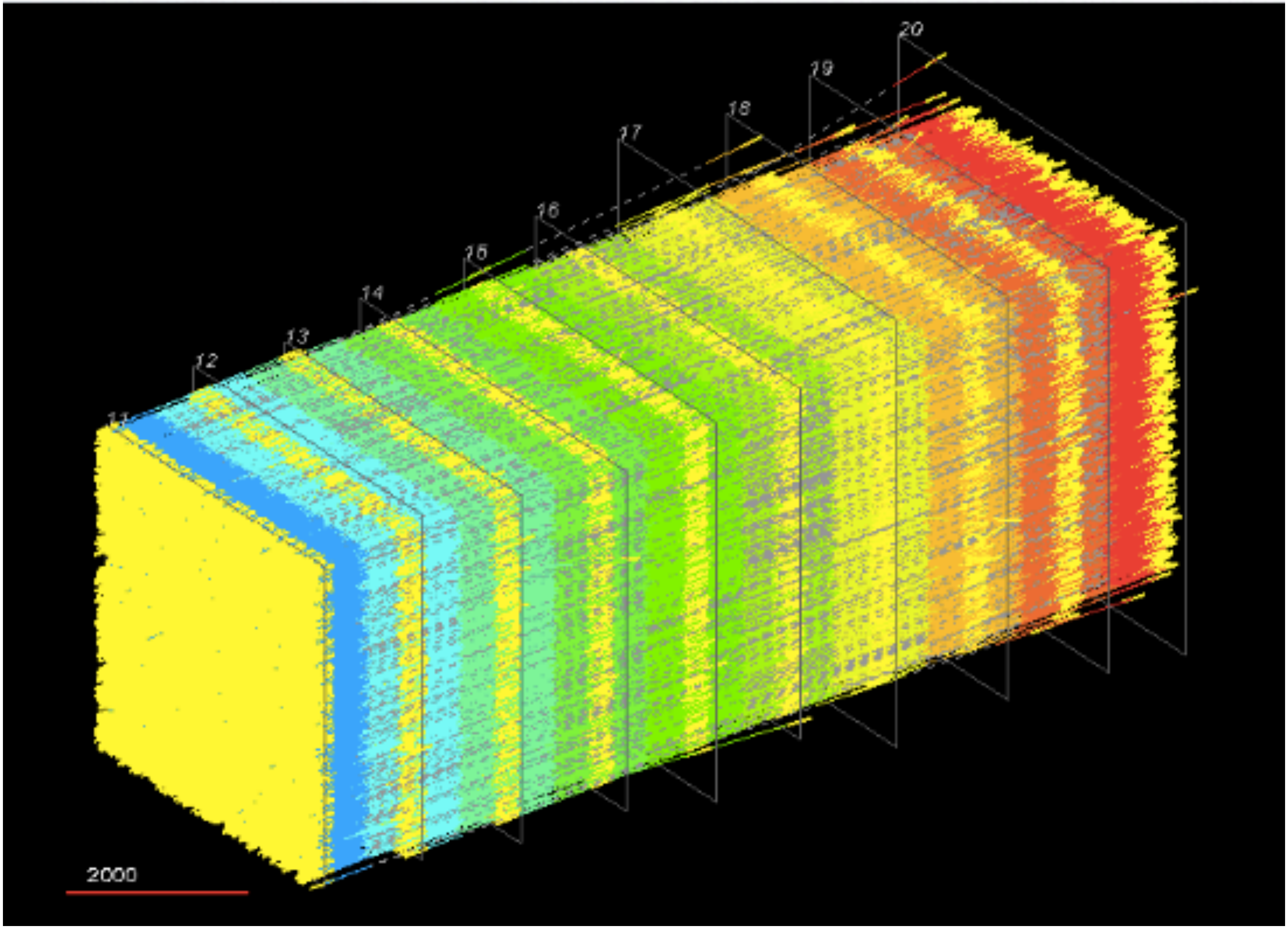
Due to bending from LHC magnets, muon flux on LOS is reduced: μ^- tend to be bent to the left, μ^+ to the right of FASER.

Background measurement

Emulsion detector was installed in June/September 2018 in tunnel, and developed/scanned in Bern University







11
12
13
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17
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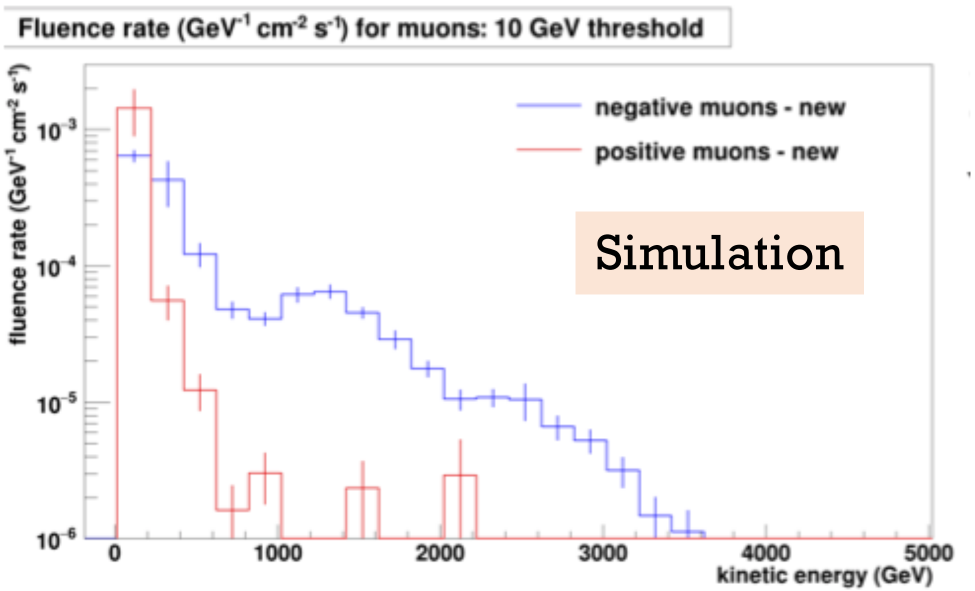
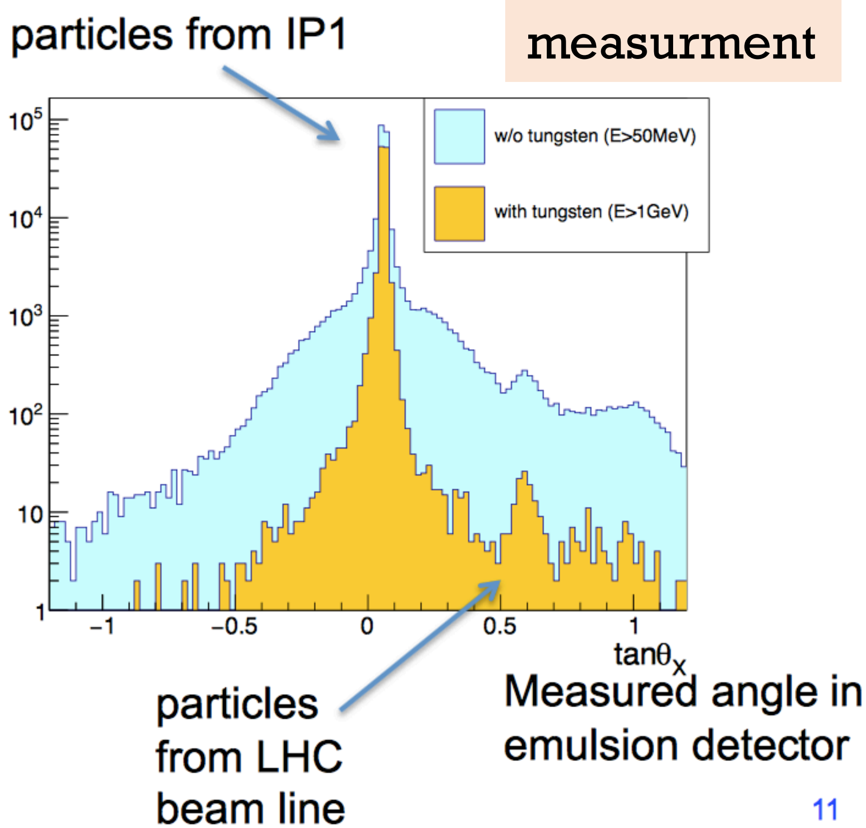
20
2000

Very low background level





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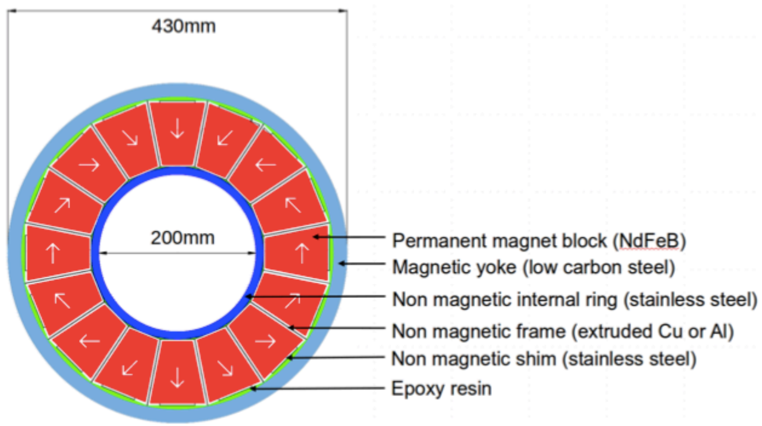
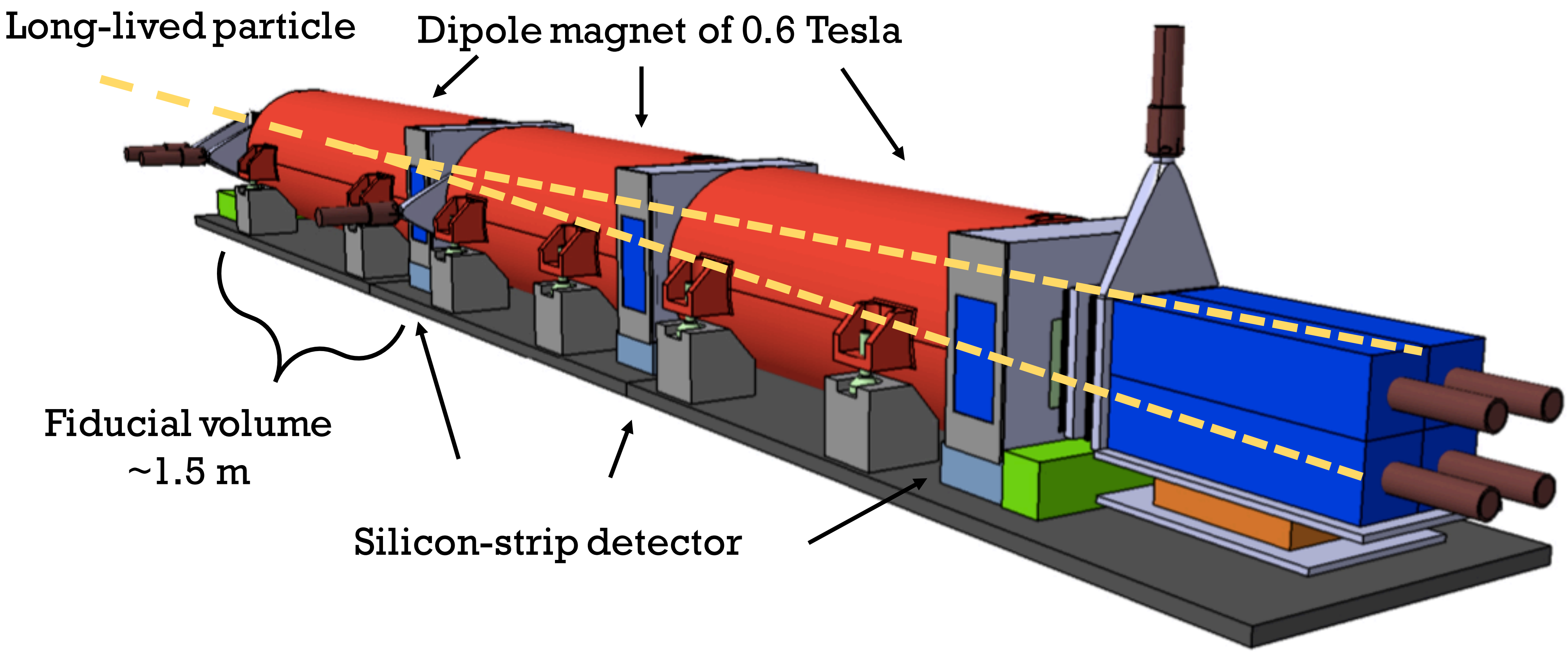
Good agreement with FLUKA simulation :
0.2 Hz / cm^2 at nominal LHC operation

Experimental setup

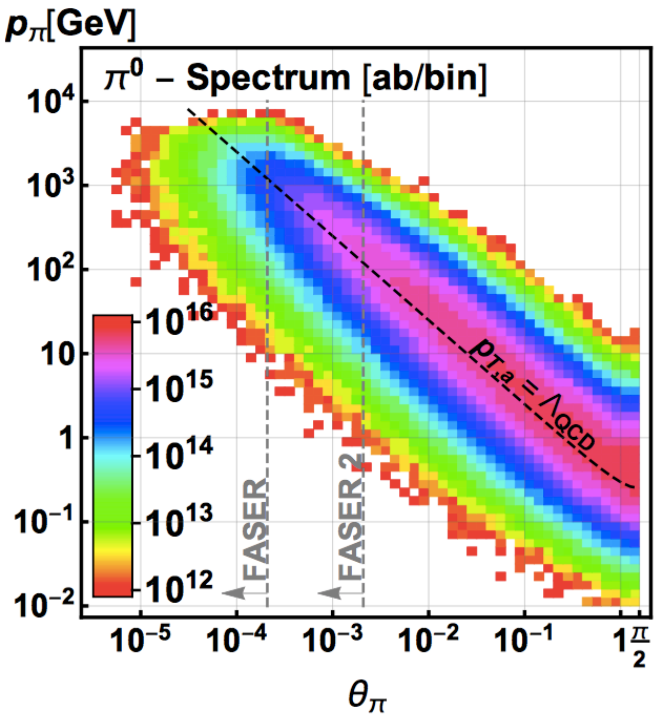


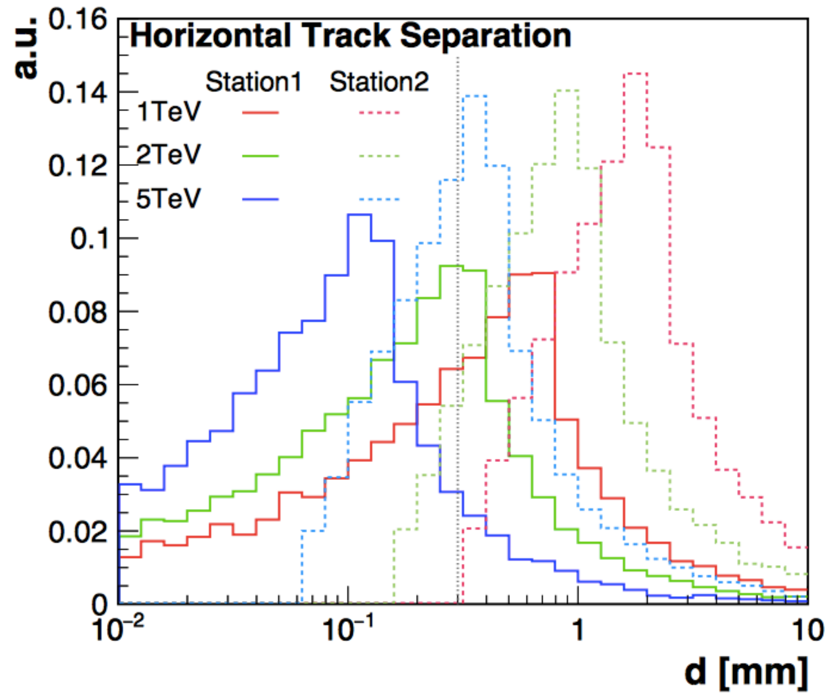


Signature of long-lived particle

For example,

- Dark photon : collimated μμ /ee / ππ pair
- Axion like particle : collimated γγ pair

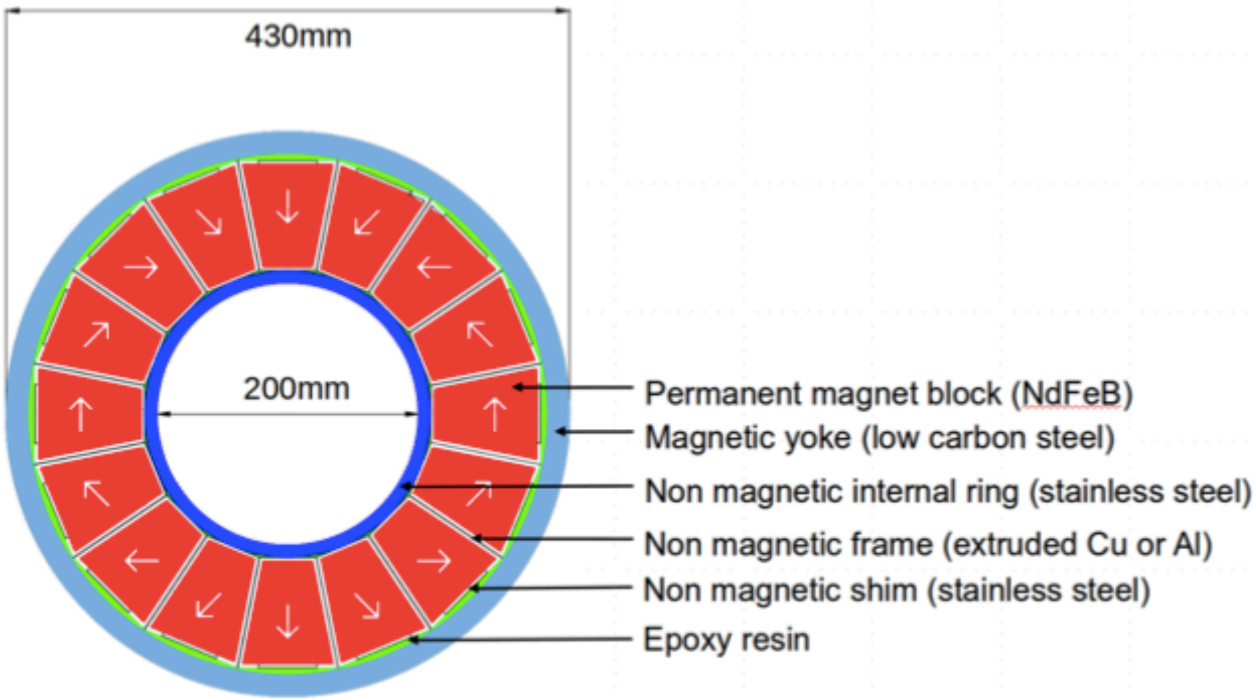


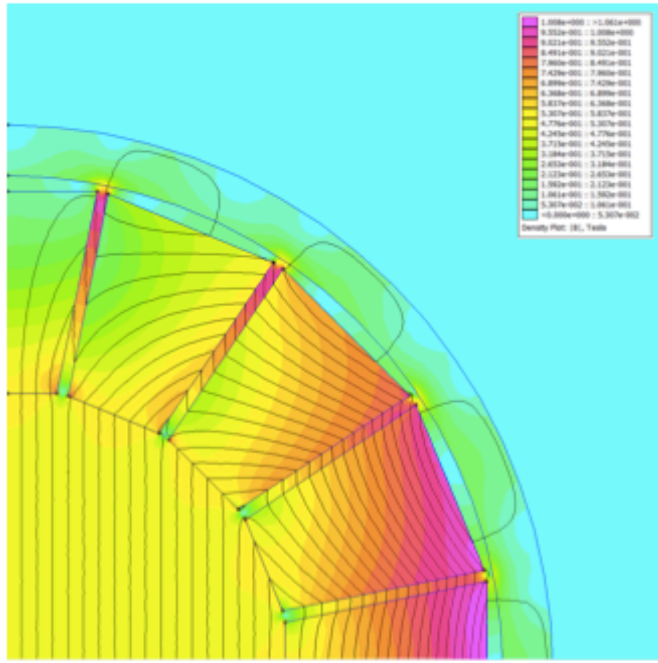


Tracker should have resolution of well below 1mm, and cover ~ 1m²

➪ Silicon strip detector would be the best candidate

Permanent magnet (0.6 Tesla)

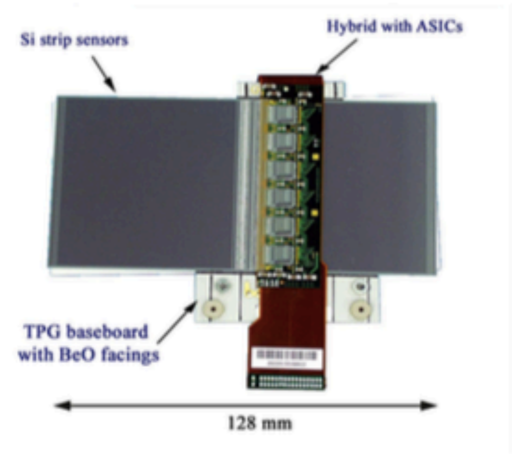




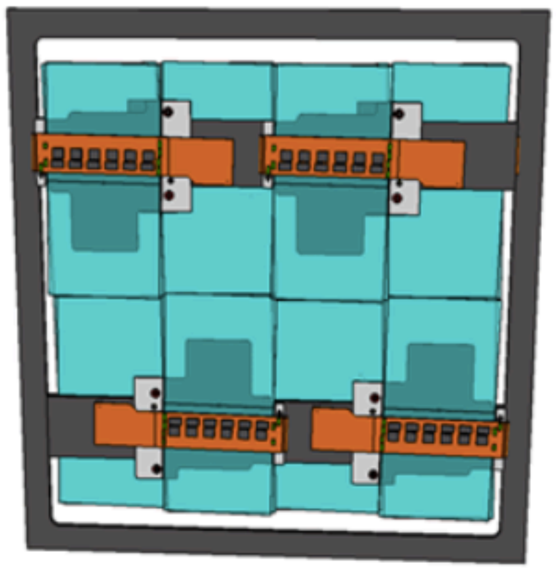
0.6 Tesla dipole-type permanent magnet

- Enough to separate two particles;
- Thin magnet part to make aperture bigger;
- No need of powering/cooling;

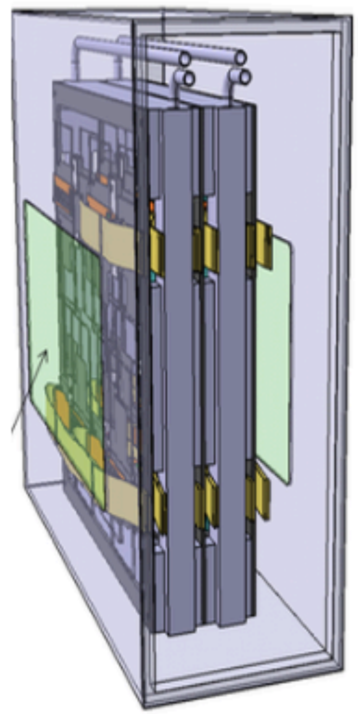
Silicon strip tracker



SCT module



Tracking layer



Tracking station

9 layer (3 x 3 station) of ATLAS SCT modules

- Each modules has two strip sensors with angle of 40 mrad
- 768 strips with 80 um pitch
- 12 ASIC per module mounted for readout

SCT spare modules for Barrel

According to the SCT barrel module paper, ~225 spare modules (2582 * 0.905 – 2112) should be stored.

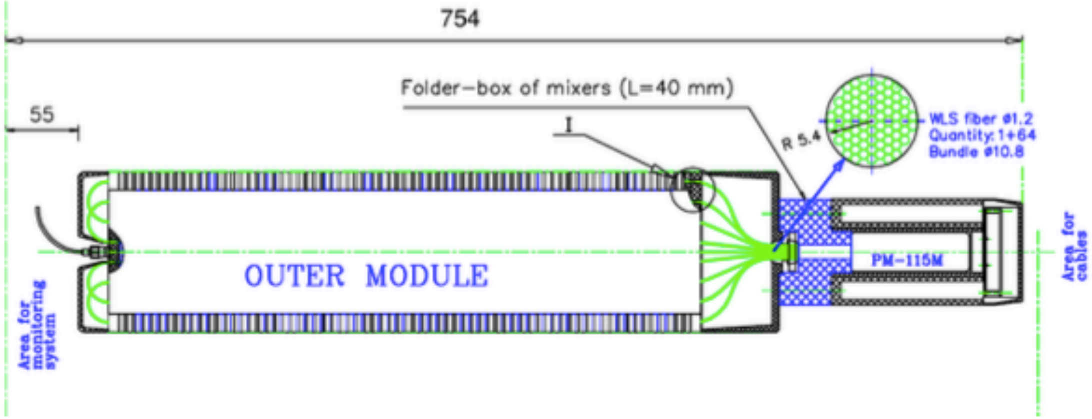
The R&D, prototyping and construction phases have been successfully completed for the barrel module project of the ATLAS SemiConductor Tracker. A total of 2582 modules have been constructed in four different SCT cluster locations during a two-year period of series production. The overall yield of modules with satisfactory mechanical and electrical performance is 90.5%. The required 2112 modules, to full ATLAS electrical and mechanical specification, have been mounted on the four barrel structures of the SCT. Module performance on the individual barrels, measured immediately after assembly, shows no degradation, with 99.8% good channels in the readout, low leakage currents and the predicted thermal performance.

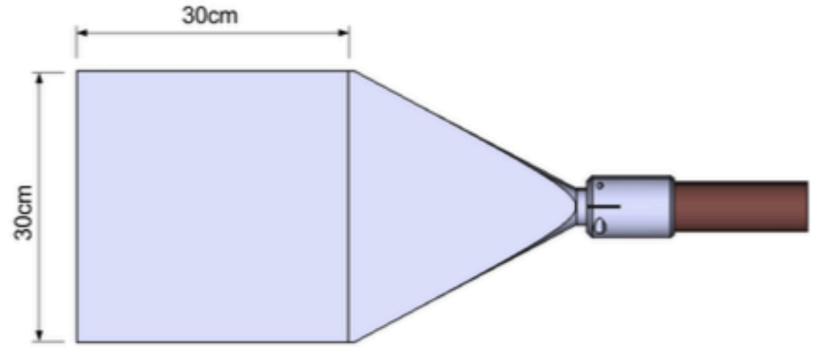
http://cds.cern.ch/record/974073/files/indet-pub-2006-005.pdf

- 196 modules are already found in CERN.

FASER had agreement to use 80 modules.

Calorimeter / Scintillator





- FASER will have an ECAL for:
  - measuring the EM energy in the event
  - electron/photon identification
  - triggering
- Will use 4 spare LHCb outer ECAL modules
  - Many thanks for LHCb for allowing us to use these!
  - Provides ~1% energy resolution for 1 TeV electrons
- Scintillators used for vetoing charged particles entering the decay volume, and for triggering
  - To be produced at CERN scintillator lab

Expected schedule

Full detector should be installed in May 2020.

- Prototype is being manufactured now.
  - e.g, patch panel, interlock, power supply, cabling for tracker
- Integration would be started from beginning of September
  - Two months for fixing any issues, and starts full production
- All components for detector would be ready by end of this year

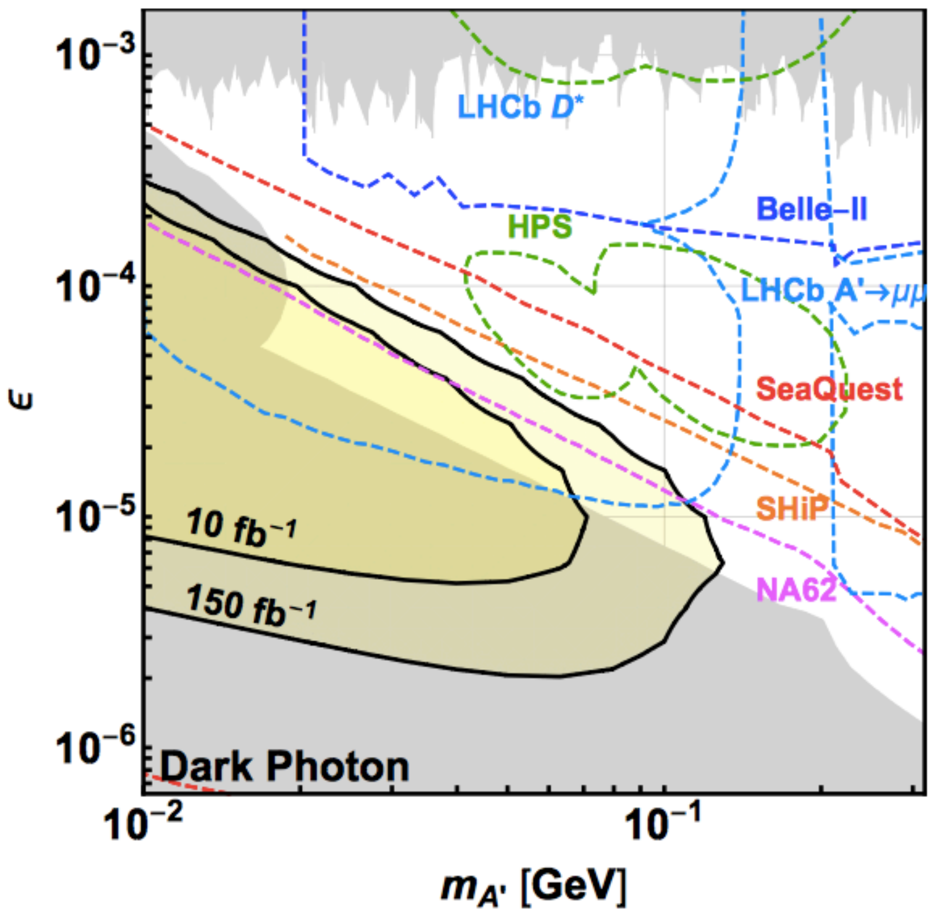
The first dipole magnet will be arrived around January

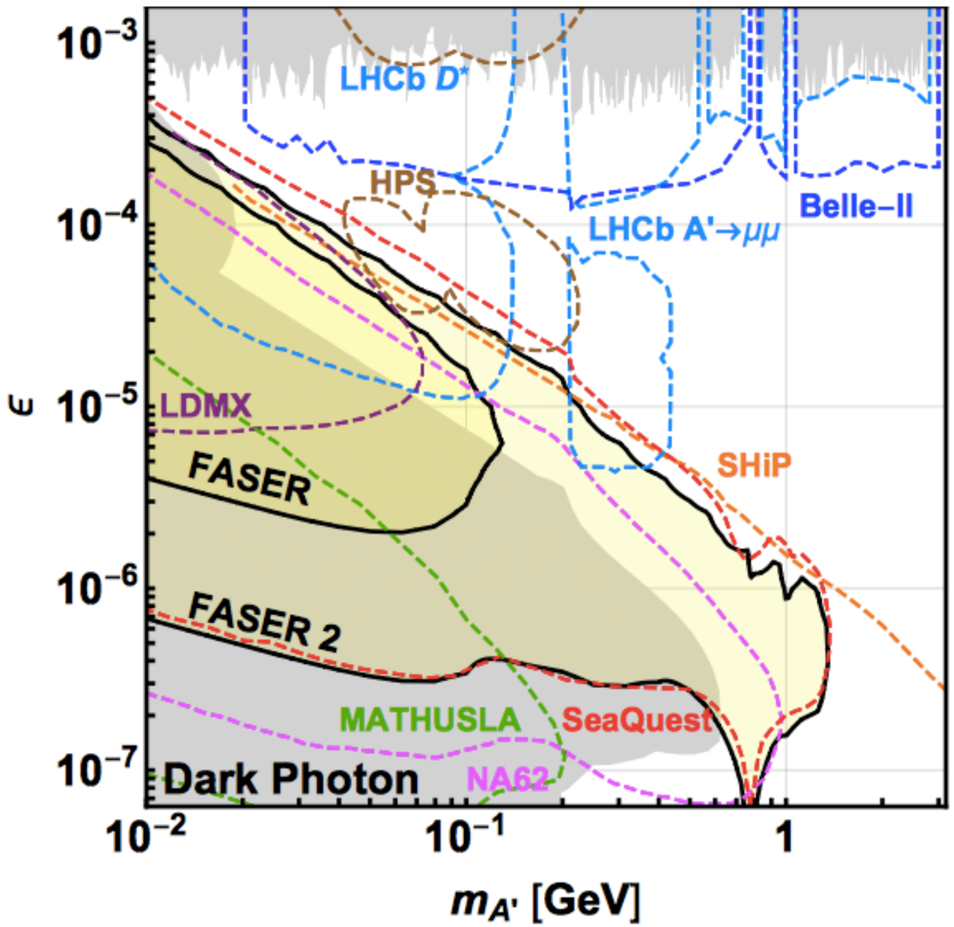
- Integrated with tracker and scintillators
- Commissioning needs to be finished by May 2020.

Very tight schedule !!!

Expected sensitivity

For Dark photon :

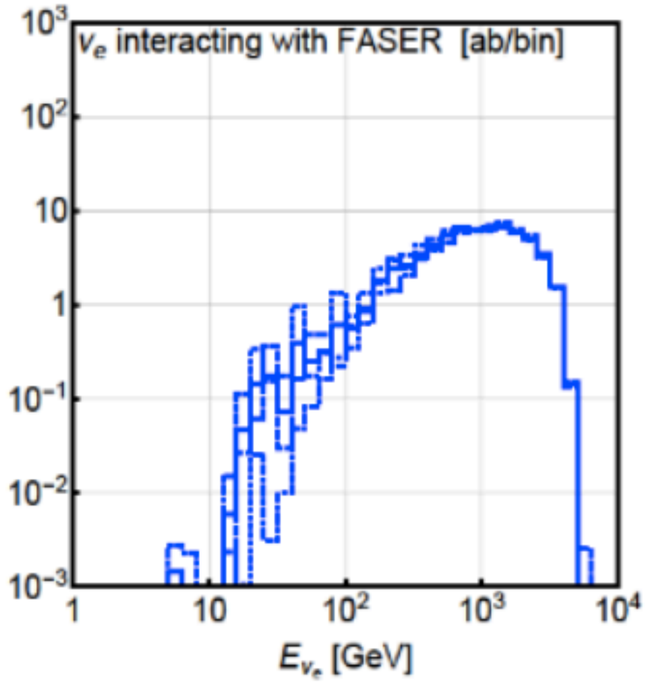




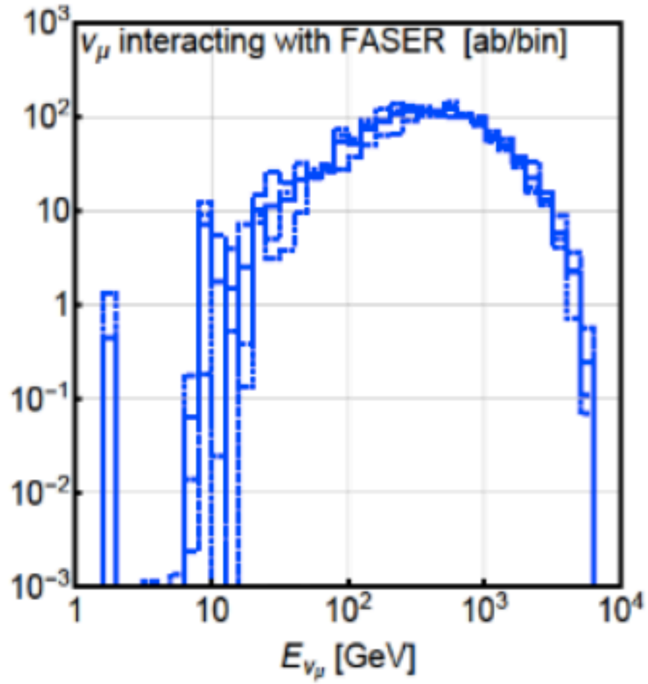
Also sensitive to various physics cases, see **arXiv:1811.12522**

How about neutrinos ?

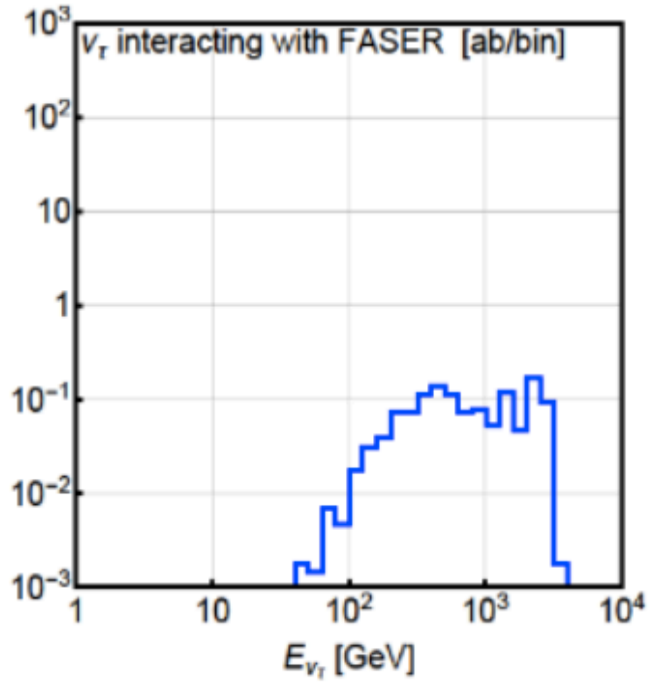
ν_e



ν_μ

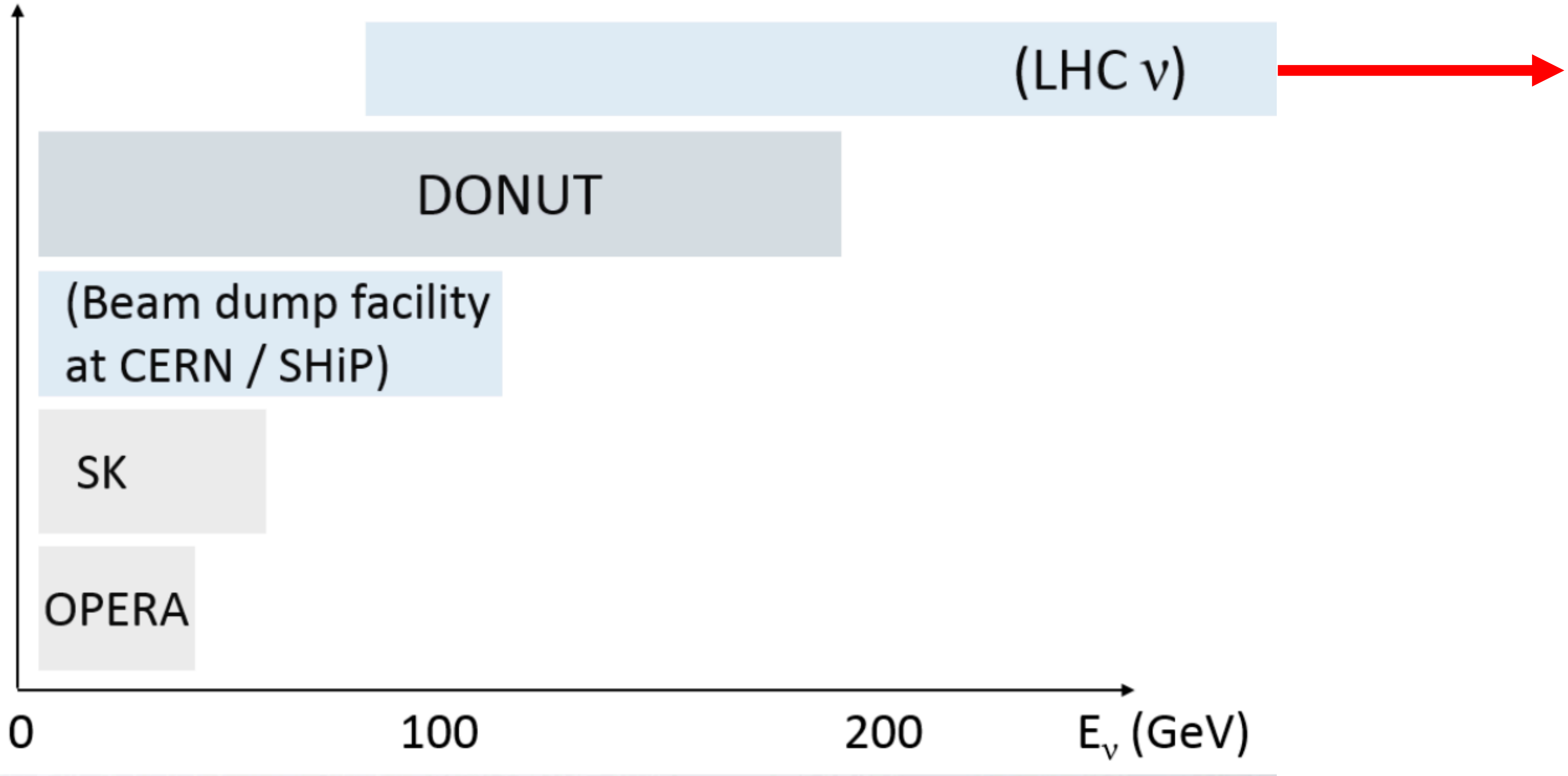


ν_τ

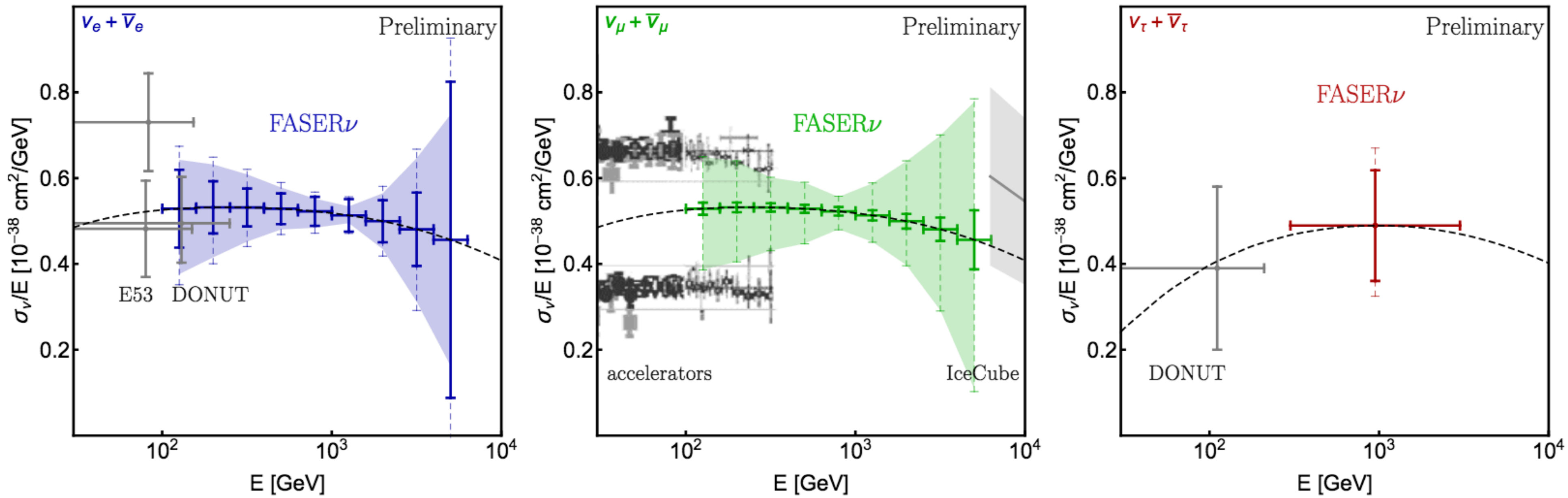


Unique energy spectrum for all flavor !!

Energy frontier for neutrino !



Prospect for cross section measurement in Run3 (2021-23)



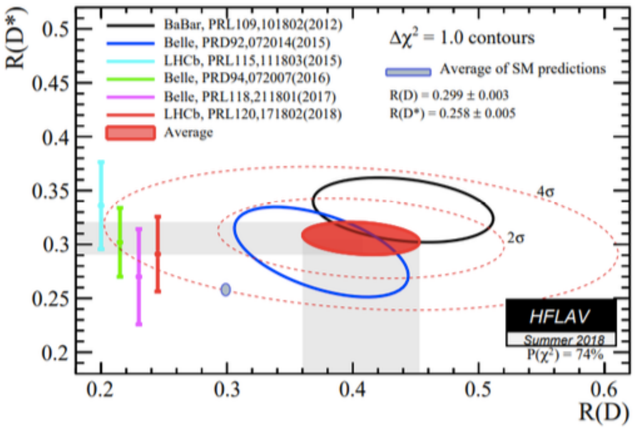
Assuming 1.2-ton tungsten/emulsion detector

Tau neutrino is more interesting !

Haven’t been exploited at all !

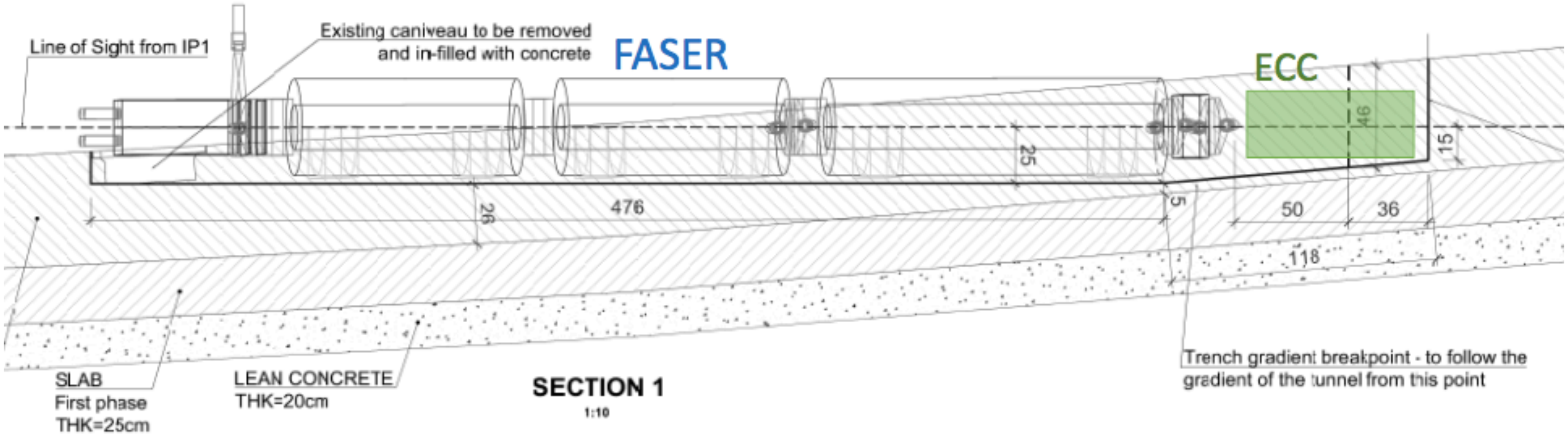
- 9 events from DONUT
- 10 events in OPERA
- No discrimination b/w tau neutrino and anti tau neutrino

May access to B anomaly ?



$$R_{D^{(*)}} = \frac{\mathcal{B}\left(\overline{B} \to D^{(*)}\tau\bar{\nu}_\tau\right)}{\mathcal{B}\left(\overline{B} \to D^{(*)}l\bar{\nu}_l\right)}$$

Emulsion in front of FASER

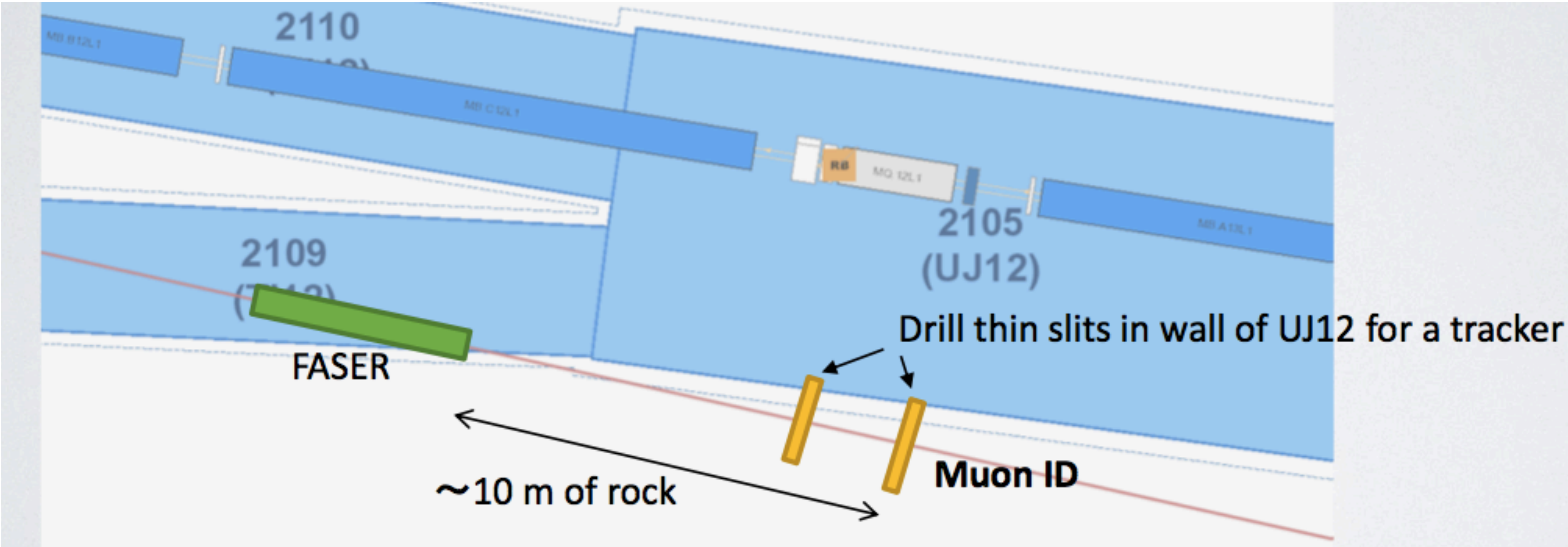


LHC Run3 (2021-2023) without muon ID

- 150 fb^{-1}/3 years → replace emulsion detectors 3 times/year
- Amount of films possibly prepared: (50 m^2 x3)/year
- Tungsten mass: 965 kg
- Number of neutrino interactions (using fluxes for R=10 cm):
  - $\nu_\mu + \overline{\nu}_\mu$: 12923 int.
  - $\nu_e + \overline{\nu}_e$: 1507 int.
  - $\nu_\tau + \overline{\nu}_\tau$: 38 int.
  - Realistically, difficult to prepare 50 m^2 x3 for 2021 → Statistics will be reduced to ~2/3

20 cm x 20 cm x 1250 layers
of 1-mm-thiack tungsten

Muon detector in rear of FASER



Summary

FASER is a proposed small, fast and cheap experiment to be installed in the LHC during 2019-2020, to take data in 2021-2023 (LHC-Run3).

- Taking advantage of already existing tunnel infrastructure and using spare detector parts from existing experiments.

It targets light, weakly-coupled new particles at low pT.

- Runs simultaneously with, and is complementary to, ATLAS/CMS, allowing to fill a possible hole in the current LHC new physics search programme.
- Also great potential for neutrino physics.

We would welcome new members to the FASER experiment !