https://twiki.cern.ch/twiki/bin/view/FASER/WebHome

FASER

ForwArd Search ExpeRiment at the LHC

Jamie Boyd (CERN)

for the FASER Collaboration

PBC Workshop Accelerator Session

17/1/2019

Supported by:

HEISING-SIMONS FOUNDATION

SIMONS FOUNDATION

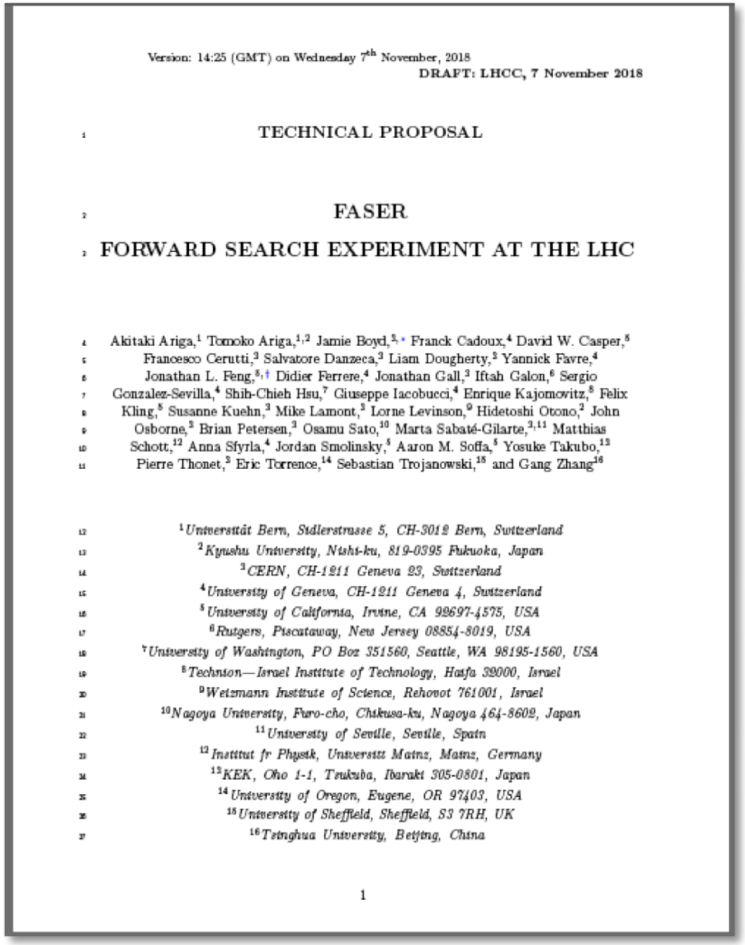
OUTLINE

FASER talk in the BSM session yesterday, covering physics and detector design.
This talk focus on more technical areas, updated since the last PBC workshop, covering:
- Background measurements / simulations
- Civil engineering work
- Transport
- Services
- Schedule

Along with the status of the experiment approval and funding.

TECHNICAL PROPOSAL

Most of what is shown here comes from the Technical Proposal (submitted to the LHCC in November 2018):



Version: 14:25 (GMT) on Wednesday 7th November, 2018
DRAFT: LHCC, 7 November 2018

TECHNICAL PROPOSAL

FASER

FORWARD SEARCH EXPERIMENT AT THE LHC

Akitaki Ariga,[1] Tomoko Ariga,[1,2] Jamie Boyd,[3,*] Franck Cadoux,[4] David W. Casper,[5] Francesco Cerutti,[3] Salvatore Danzeca,[3] Liam Dougherty,[3] Yannick Favre,[4] Jonathan L. Feng,[5,†] Didier Ferrere,[4] Jonathan Gall,[3] Iftah Galon,[6] Sergio Gonzalez-Sevilla,[4] Shih-Chieh Hsu,[7] Giuseppe Iacobucci,[4] Enrique Kajomovitz,[8] Felix Kling,[5] Susanne Kuehn,[3] Mike Lamont,[3] Lorne Levinson,[9] Hidetoshi Otono,[2] John Osborne,[3] Brian Petersen,[3] Osamu Sato,[10] Marta Sabaté-Gilarte,[3,11] Matthias Schott,[12] Anna Sfyrla,[4] Jordan Smolinsky,[5] Aaron M. Soffa,[5] Yosuke Takubo,[13] Pierre Thonet,[3] Eric Torrence,[14] Sebastian Trojanowski,[15] and Gang Zhang[16]

[1] *Universität Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland*
[2] *Kyushu University, Nishi-ku, 819-0395 Fukuoka, Japan*
[3] *CERN, CH-1211 Geneva 23, Switzerland*
[4] *University of Geneva, CH-1211 Geneva 4, Switzerland*
[5] *University of California, Irvine, CA 92697-4575, USA*
[6] *Rutgers, Piscataway, New Jersey 08854-8019, USA*
[7] *University of Washington, PO Box 351560, Seattle, WA 98195-1560, USA*
[8] *Technion—Israel Institute of Technology, Haifa 32000, Israel*
[9] *Weizmann Institute of Science, Rehovot 761001, Israel*
[10] *Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8602, Japan*
[11] *University of Seville, Seville, Spain*
[12] *Institut fr Physik, Universitt Mainz, Mainz, Germany*
[13] *KEK, Oho 1-1, Tsukuba, Ibaraki 305-0801, Japan*
[14] *University of Oregon, Eugene, OR 97403, USA*
[15] *University of Sheffield, Sheffield, S3 7RH, UK*
[16] *Tsinghua University, Beijing, China*

1

https://cds.cern.ch/record/2651328/
https://arxiv.org/abs/1812.09139

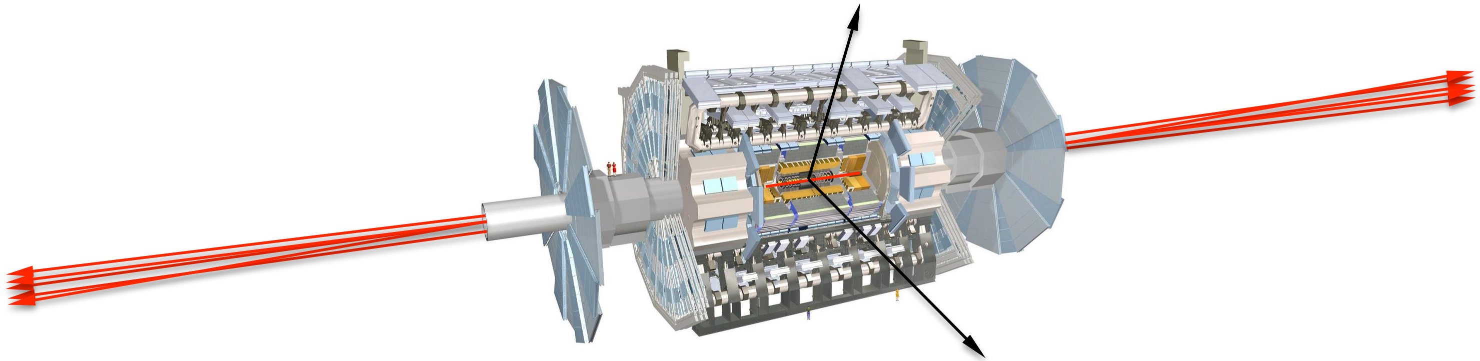
Or work that has been done since then

arXiv:1708.09389

FASER: THE IDEA

- New physics searches at the LHC focus on high p_T. This is appropriate for heavy, strongly interacting particles
  - σ ~ fb to pb → In Run-3 N ~ 10^2 – 10^5, produced ~isotropically

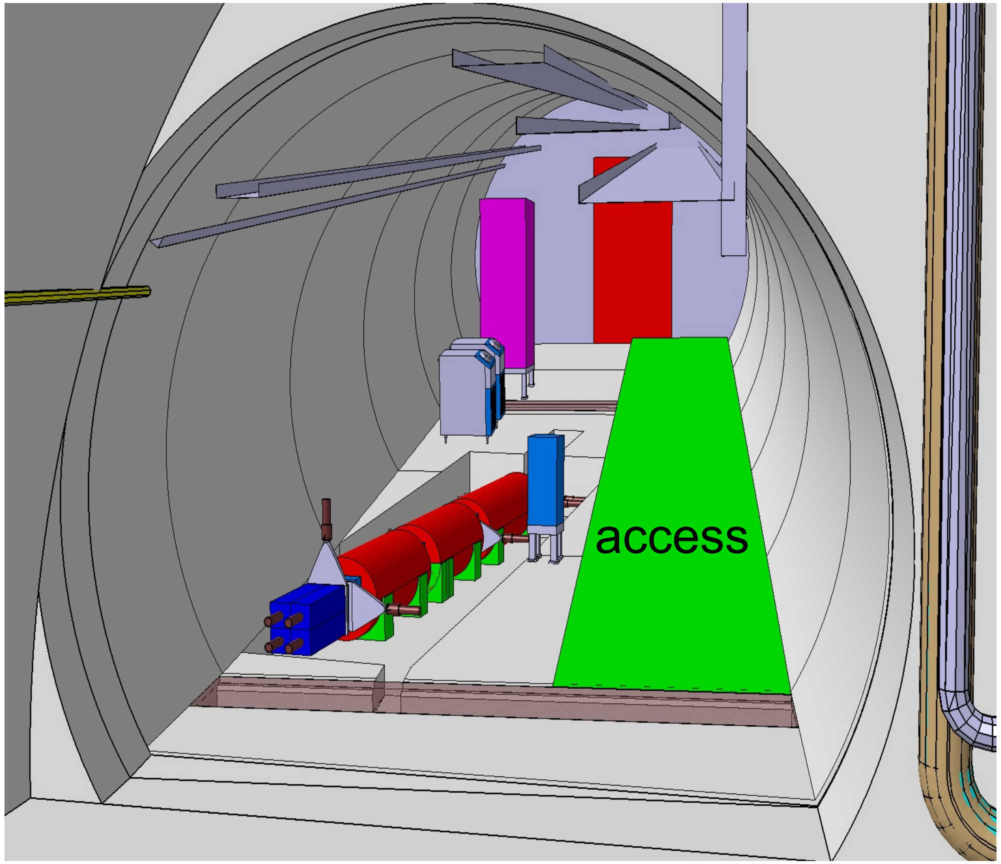
- However, if new particles are light and weakly interacting, this may be completely misguided. Instead can exploit
  - σ_{inel} ~ 100 mb → In Run-3 N ~ 10^{16}, $\theta \sim \Lambda_{QCD}$ / E ~ 250 MeV / TeV ~ mrad

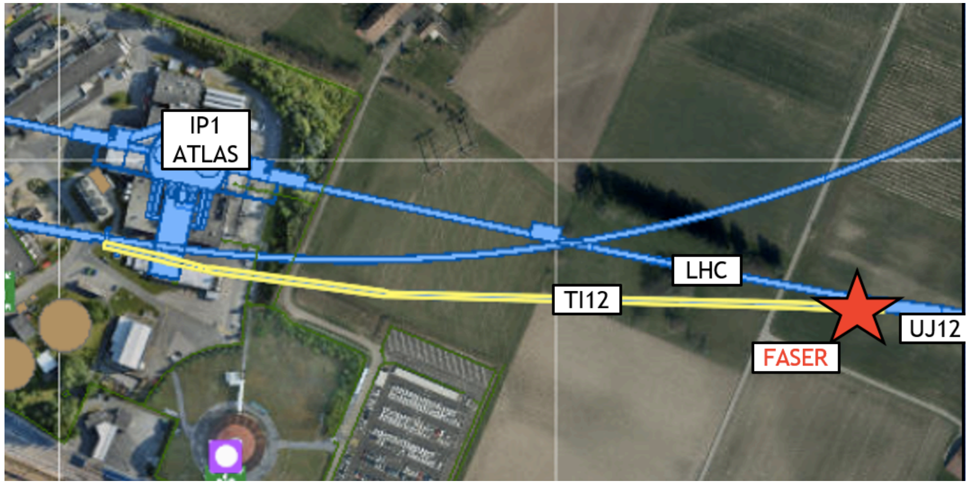


- FASER is a proposed experiment designed to cover this scenario at the LHC
- Detector to be placed 480m from IP1 directly on the beam collision axis line of sight (LOS) with transverse radius of only 10cm covering the mrad regime

For more details about FASER physics/detector talk in yesterdays BSM session!

FASER IN TI12





TI12 tunnel condemned, but FASER would be situated in region before tunnel is sealed.
Do not plan to re-open tunnel between SPS and LHC.
Access to FASER along LHC tunnel (from point-1), and over machine/QRL in UJ12.

TI12 slopes up from LHC to SPS, for detector to be situated on LOS (as required from physics), need a small amount of digging into floor of TI12 tunnel.

BEAM BACKGROUNDS - SIMULATION

- FLUKA simulations and in situ measurements have been used to assess the backgrounds expected in FASER
- FLUKA simulations studied particles entering FASER from:
  - IP1 collisions
  - off-orbit protons hitting beam pipe aperture in dispersion suppressor (close to FASER) (following diffractive interactions in IP1)
  - beam-gas interactions
- Expect a flux of high energy muons (E>10 GeV) of $0.4 cm^{-2}s^{-1}$ at FASER for $2e34 cm^{-2}s^{-1}$ luminosity from IP1 collisions
  - Completely dominated by particles from collisions

Updates to FLUKA studies since last PBC workshop:

- reduce energy threshold for particles rates in FASER (100 GeV -> 10 GeV)

- include neutrino flux calculations

- improve biassing technique to improve statistical uncertainty

- consider LHC layout (previously HL-LHC)

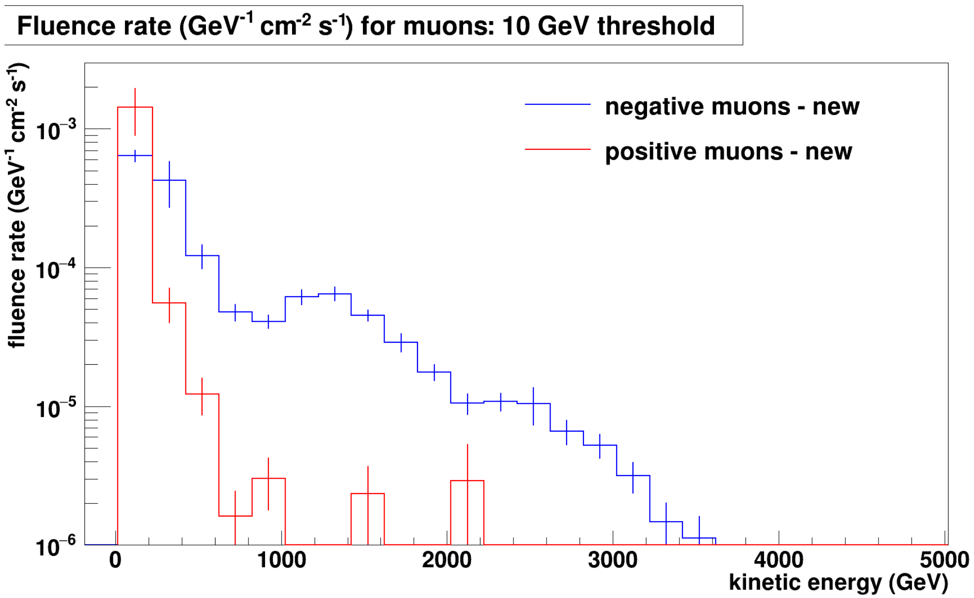
    - as expected not a large effect

Simulations produced for TI18 tunnel (rather than TI12 which is now the preferred FASER location) – but expectation (now validated with in situ measurements) that rates should be the same for both locations.

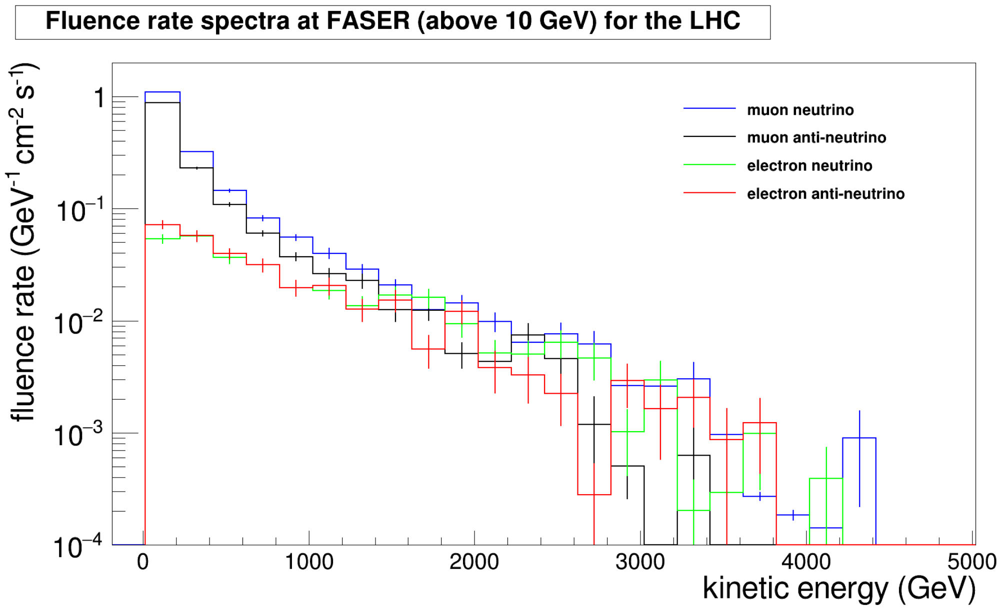
Many thanks to FLUKA team (STI-BMI), with PBC support, for these studies!

BEAM BACKGROUNDS - SIMULATION

- FLUKA simulations and in situ measurements have been used to assess the backgrounds expected in FASER
- FLUKA simulations studied particles entering FASER from:
  - IP1 collisions
  - off-orbit protons hitting beam pipe aperture in dispersion suppressor (close to FASER) (following diffractive interactions in IP1)
  - beam-gas interactions
- Expect a flux of high energy muons (E>10 GeV) of $0.4cm^{-2}s^{-1}$ at FASER for $2e34cm^{-2}s^{-1}$ luminosity from IP1 collisions
  - Completely dominated by particles from collisions



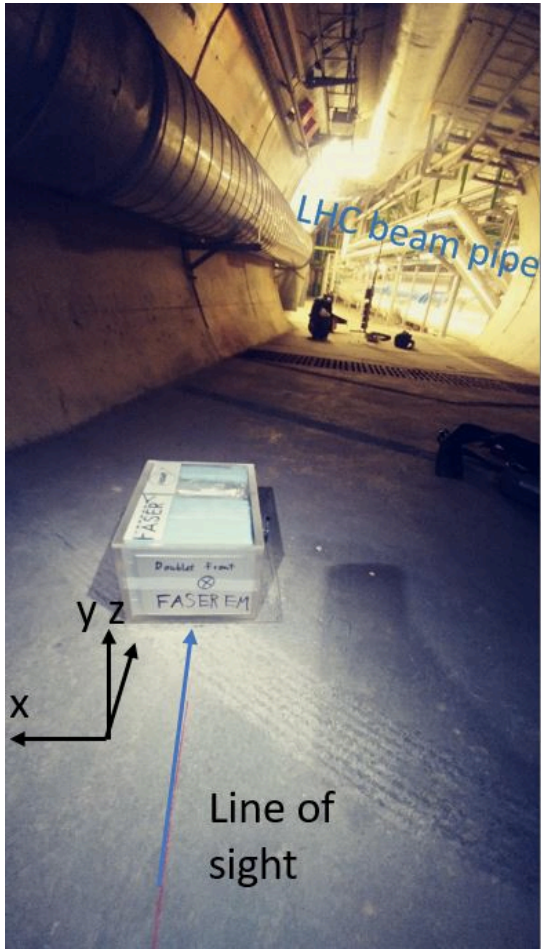
Large muon charge asymmetry at FASER

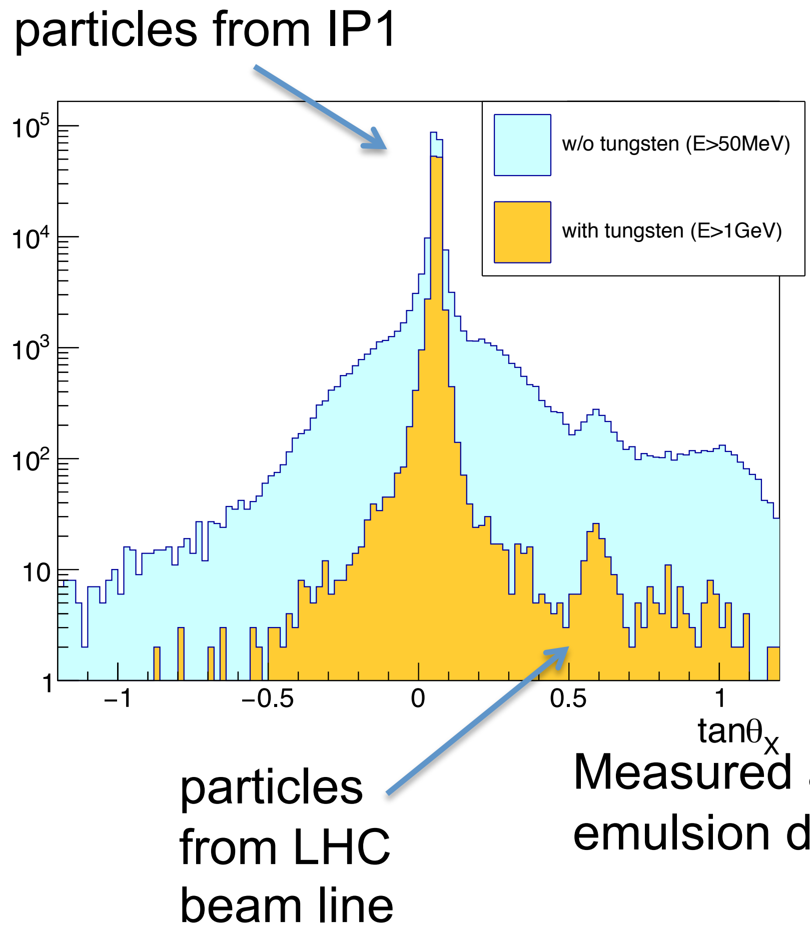


Huge flux of high energy neutrinos

BEAM BACKGROUNDS - MEASUREMENTS

- Measurements using emulsion detectors installed in TI18 & TI12 in 2018 running confirm expected particle flux
- Measurements using TimePix BLM in TI18 confirm that particle flux is correlated with luminosity in IP1





Measured angle in emulsion detector

BEAM BACKGROUNDS - MEASUREMENTS

- Measurements using emulsion detectors installed in TI18 & TI12 in 2018 running confirm expected particle flux
- Measurements using TimePix BLM in TI82 confirm that particle flux is correlated with luminosity in IP1

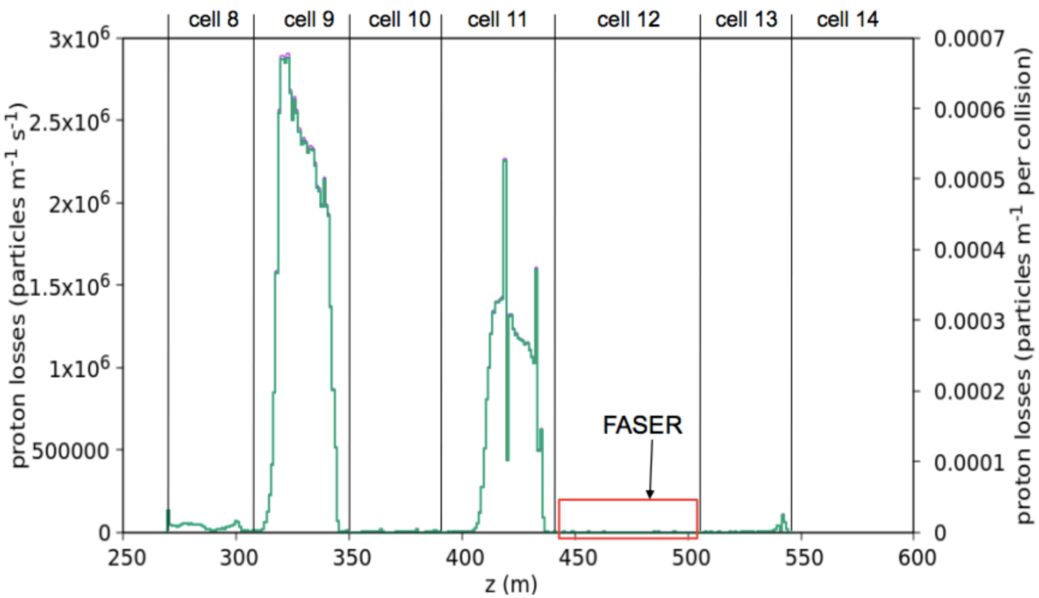
Period	Luminosity $[10^{34}\ \mathrm{s}^{-1}\ \mathrm{cm}^{-2}]$	Counting Rate $[\mathrm{s}^{-1}]$	Counting Rate/Luminosity $[10^{-34}\ \mathrm{cm}^{2}]$
No beam	-	0.16	-
Beam (no collisions)	-	0.55	-
Collisions	1.8	7.0	4.0
Collisions	1.3	4.8	3.8
Collisions	0.8	3.3	4.2
Collisions	0.6	2.7	4.3
Collisions	0.5	2.2	4.1

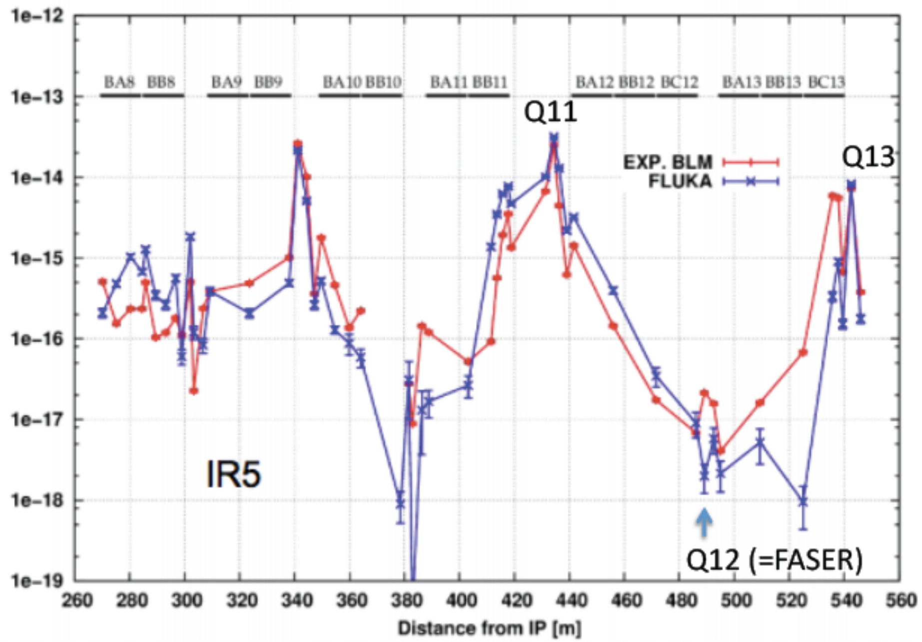
TABLE III. Preliminary results from the TimePix detector installed in TI18, indicating that the main particle rate is proportional to luminosity in IP1. This also shows a small, but significant, increase in rate with non-colliding beam, compared to no beam in the machine. Beam (no collisions) corresponds to a full machine (2556 bunches) at the start of a physics fill, providing a total intensity of 2.7×10^{14} protons per beam.

Many thanks to the BE-BI team for installing/analyzing TimePix BLM detector

RADIATION LEVEL

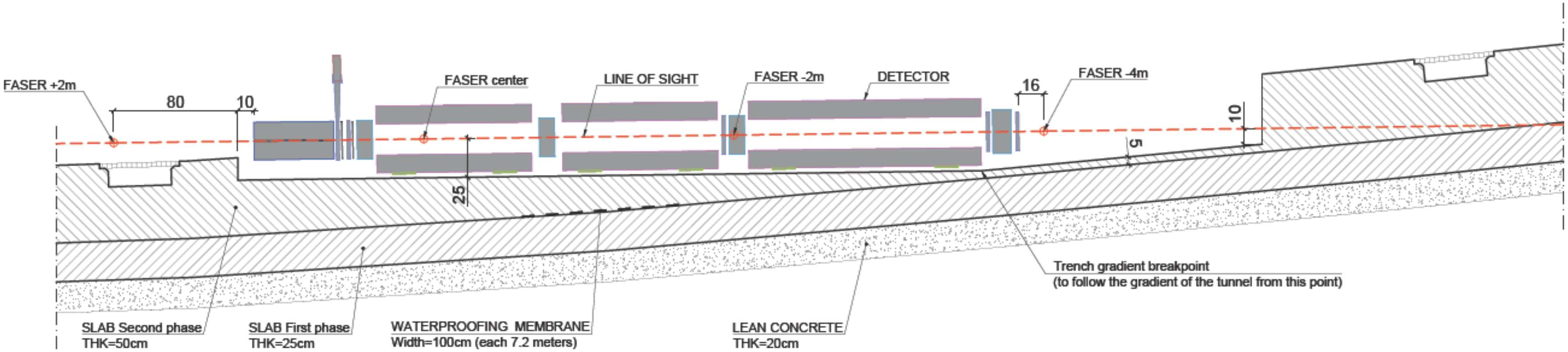
- Radiation level predicted to be very low in TI12 due to dispersion function of LHC at this location
- Measurements by BatMon radiation monitor (in TI12 & TI18) in 2018 running confirm FLUKA expectations of:
  - less than 5 x 10^{-3} Gy/year
  - less than 5 x 10^{7} 1 MeV neutron equivalent fluence / year
- FASER detector does not need radiation hard electronics

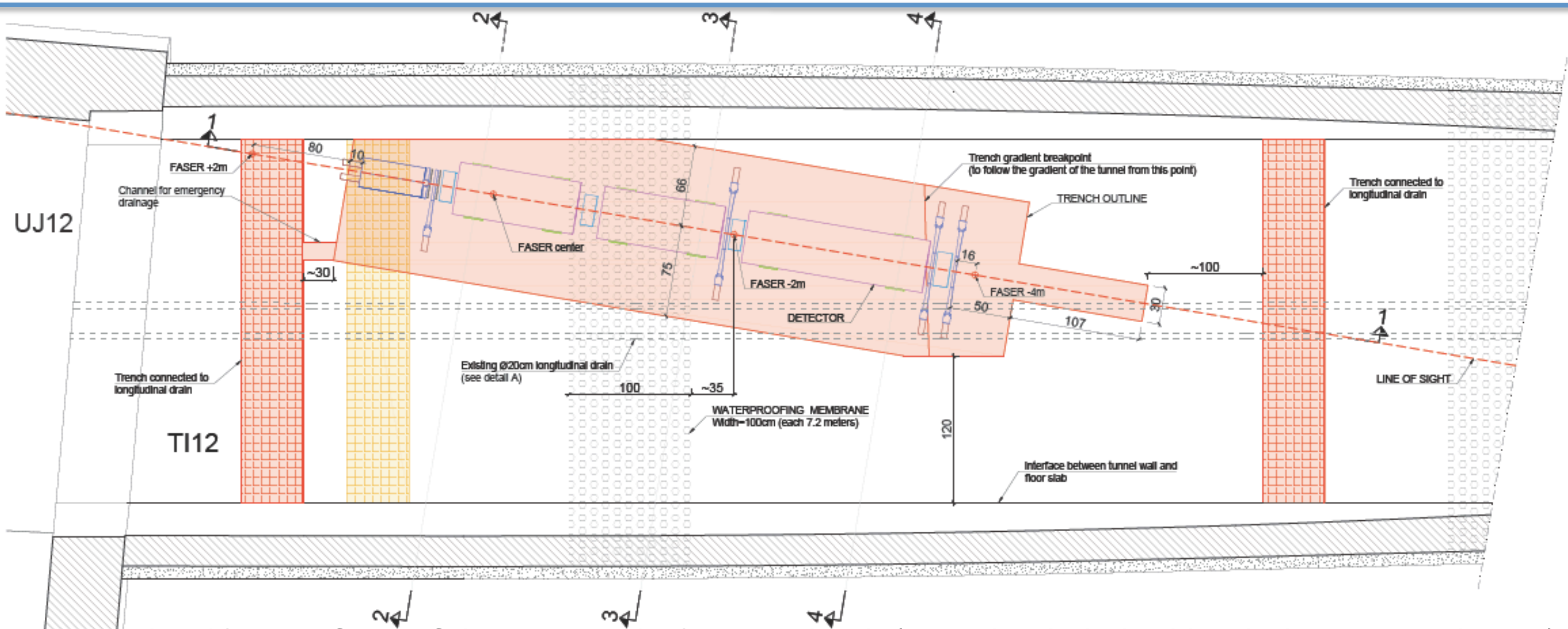




Many thanks to the SMM-RME team for installing analyzing the BatMon detectors.

CIVIL ENGINEERING WORK





Trench depth ~46cm at front of detector and ~25cm at back (max depth limited by drainage membrane).
Size ~1.51m x 5.5m.
Many thanks to CE team (SE-FAS), supported by PBC, for work planning the CE works for FASER!

CE WORKS - ONGOING WORK

Ongoing planning for CE work as in Technical Proposal

- A suitably detailed structural analysis of the existing tunnel should be carried out to confirm that the works will have no impact on tunnel stability or to allow the design of local strengthening measures necessary.
- A ground penetrating radar survey of the existing tunnel invert structure should be undertaken to confirm the exact depth of the existing drainage and drainage membrane to facilitate works and confirm the design.
- A CCTV survey of the existing drainage systems should be carried out to confirm their condition and operation prior to connection.
- Representative samples will need to be taken to determine the level of concrete activation.

CE WORKS - ONGOING WORK

Ongoing planning for CE work as in Technical Proposal

- A suitably detailed structural analysis of the existing tunnel should be carried out to confirm that the works will have no impact on tunnel stability or to allow the design of local strengthening measures necessary.
- A ground penetrating radar survey of the existing tunnel invert structure should be undertaken to confirm the exact depth of the existing drainage and drainage membrane to facilitate works and confirm the design.
- A CCTV survey of the existing drainage systems should be carried out to confirm their condition and operation prior to connection.
- Representative samples will need to be taken to determine the level of concrete activation.

First results from structural analysis back from ARUP. Confirm that, as expected, some local strengthening in tunnel will be needed.
Discussion ongoing with ARUP to agree a scope for a mitigation design and commission some additional work to determine the best option for strengthening given the constraints. There are a number of ideas as to how this could be achieved.

CE WORKS - ONGOING WORK

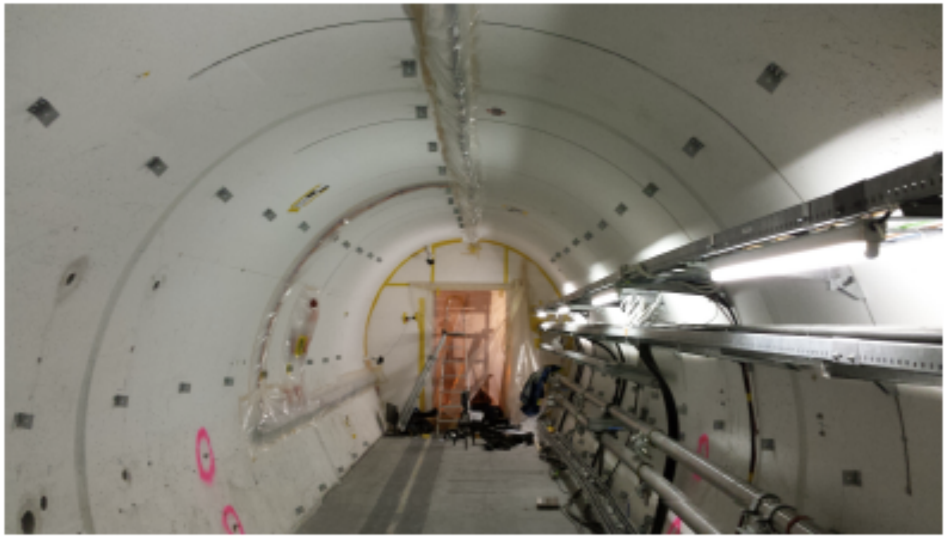
Ongoing planning for CE work as in Technical Proposal

- A suitably detailed structural analysis of the existing tunnel should be carried out to confirm that the works will have no impact on tunnel stability or to allow the design of local strengthening measures necessary.
- A ground penetrating radar survey of the existing tunnel invert structure should be undertaken to confirm the exact depth of the existing drainage and drainage membrane to facilitate works and confirm the design.
- A CCTV survey of the existing drainage systems should be carried out to confirm their condition and operation prior to connection.
- Representative samples will need to be taken to determine the level of concrete activation.

Site visit by CE experts this week. First results suggest drain slightly less deep than originally thought. But does not change situation much.

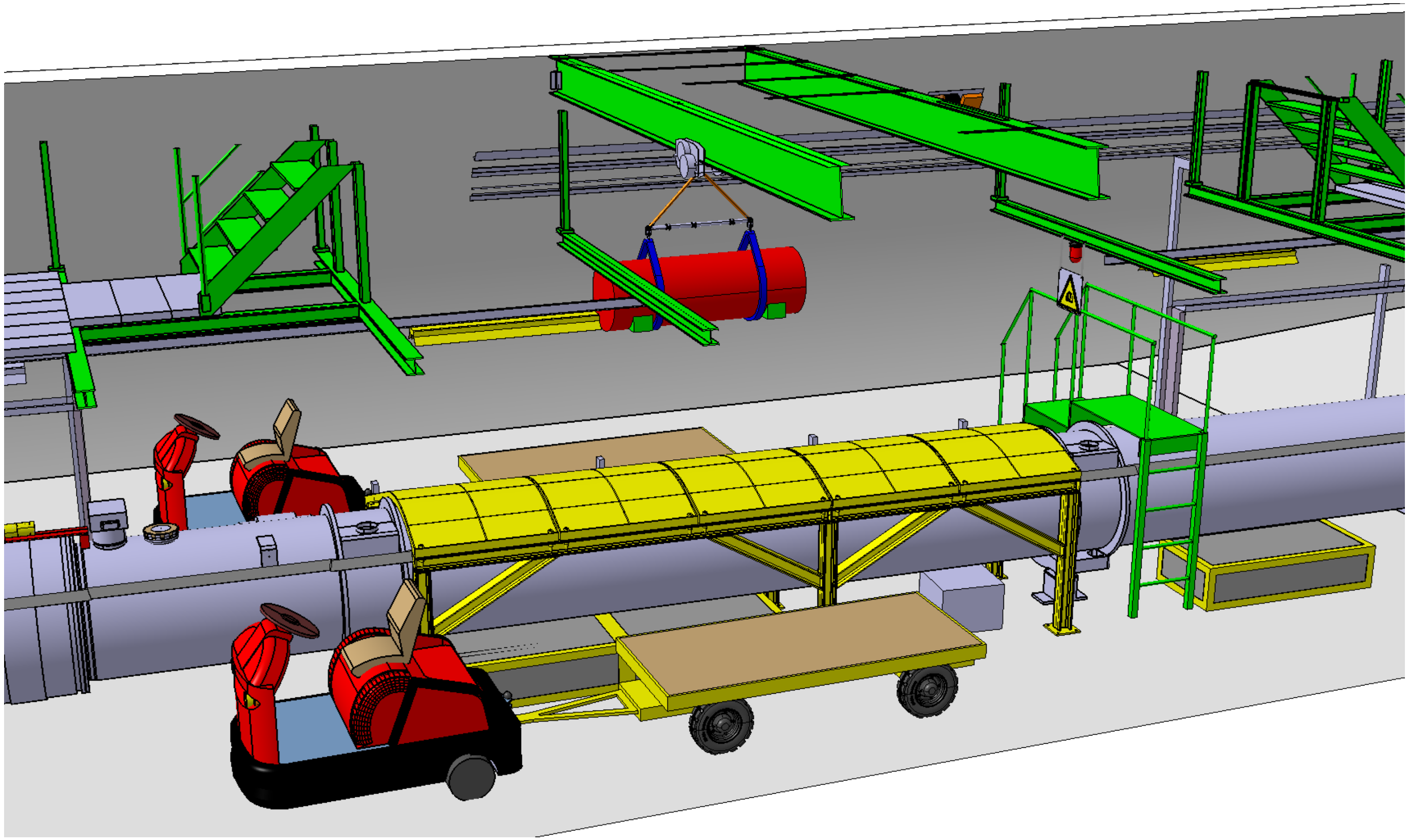
Civil Engineering works – Dust Suppression

- Concerns raised about dust from CE works
- Dust suppression strategy:
  - Seal off TI12 with double SAS (filtered ventilation) using asbestos contractor (who have necessary expertise)
  - Use water suppression / rig-mounted diamond coring
  - Will not carry out CE works during critical sensitive work in LHC (DISMAC campaign)



TRANSPORT

Transport of detector components to TI12 goes via P1 (PM18 lift).
In UJ12 the components need to be carried over the LHC and QRL.
Preliminary transport study for heaviest piece (1.5m long / 1.5tonne permanent magnet). Many thanks to HE-PO team for this work.
Schedule transport before cool down of sector (mid-June 2020).
Protection to be installed over LHC/QRL in case of failure during handling.

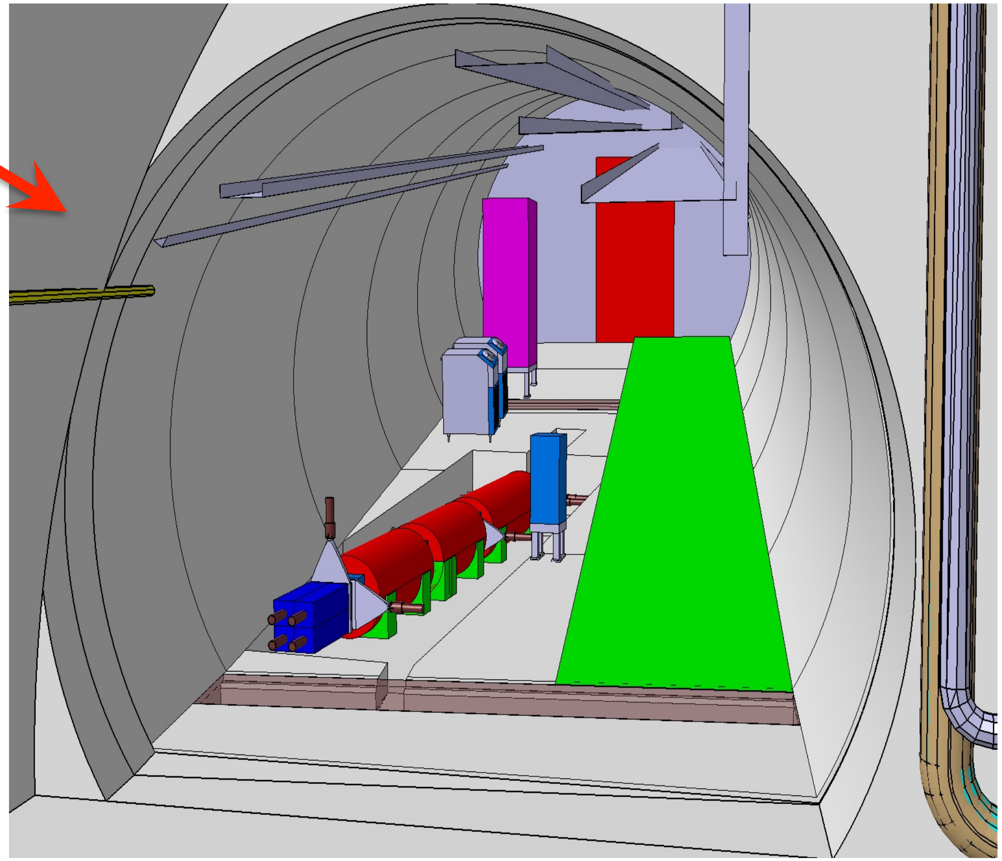


OTHER (SMALL) WORKS

- Remove unused ventilation ducts from TI12
- Uninstall lighting / unused cable trays
- Move cable trays
- Move pasarelle / Install handling equipment
- Install lights in TI12
- Install 16A power breaker (from 50m away)
- Connection of compressed air to TI12 (50/100m away)
- Installation of optical fibers to SR1 (point-1 surface building)

Have discussed the above work with CERN technical teams (EN-EL / EN-CV and integration), but have not integrated this work into LS2 planning yet. Engineering Change Request in preparation.

REALISING FASER IN LS2



CURRENT STATUS

- FASER Letter of Intent submitted to the LHCC in July
  - discussed in Sept. meeting (arXiv:1811.10243)
- Technical Proposal submitted to LHCC in Oct
  - discussed in Nov. meeting (arXiv:1812.09139)
- LHCC positive about scientific and technical aspects of the experiment:

> - The **LHCC considers** the FASER physics case valid, offering a great opportunity to explore new domains of BSM phenomena, cheaply and rapidly.

> - The **LHCC recommends** approving the FASER proposal. Regular updates on the project status should be provided to the LHCC.

- Positively discussed at CERN Research Board in December
- Aiming for approval at Research Board in March, contingent on getting FASER activities into LS2 schedule (and approved by LS2C)
- $2M funding secured contingent on CERN approval
  - Detector cost ~800k, additional funding for graduate students

HEISING-SIMONS FOUNDATION SIMONS FOUNDATION

SUMMARY AND OUTLOOK

- FASER is a proposed small, fast and cheap experiment to be installed in the LHC during LS2, to take data in Run 3
  - Taking advantage of already existing tunnel infrastructure and using spare detector parts from existing experiments
  - It targets light, weakly-coupled new particles and is complementary to ATLAS/CMS, allowing to fill a possible hole in the current LHC new physics search programme

- FASER has been positively reviewed by the LHCC, and is aiming for formal approval at the CERN Research Board in March

- FASER installation in LS2 is tight, but work fits into current LS2 schedule, critical path:
  - Civil Engineering work for 6 weeks + 4 weeks (outside working hours) in Jan/Feb 2020
  - Transport of heavy components into TI12 before Sector-81 cool-down (mid-June 2020)

LHCC recommendations

Extract from LHCC minutes from November meeting:

- The **LHCC congratulates** FASER on the timely submission of the TP and the progress made since then.
- The **LHCC finds** that the detector is reasonably well defined, with some contingency included in the cost estimate. The schedule looks somewhat aggressive but realistic.
- The **LHCC observes** that although each of the systems has a knowledgeable and committed core team behind it, additional resources especially in terms of students and postdocs will be required to operate the detector and carry out the physics analysis. The commitment of the engineering resources by the University of Geneva group is a notable strength of the team.
- The **LHCC notes** that in order to minimize schedule risk, the magnets must be ordered and constructed as soon as possible using foundation funding which is contingent on approval of FASER.
- The **LHCC recommends** approving the FASER proposal. Regular updates on the project status should be provided to the LHCC.

THE FASER COLLABORATION

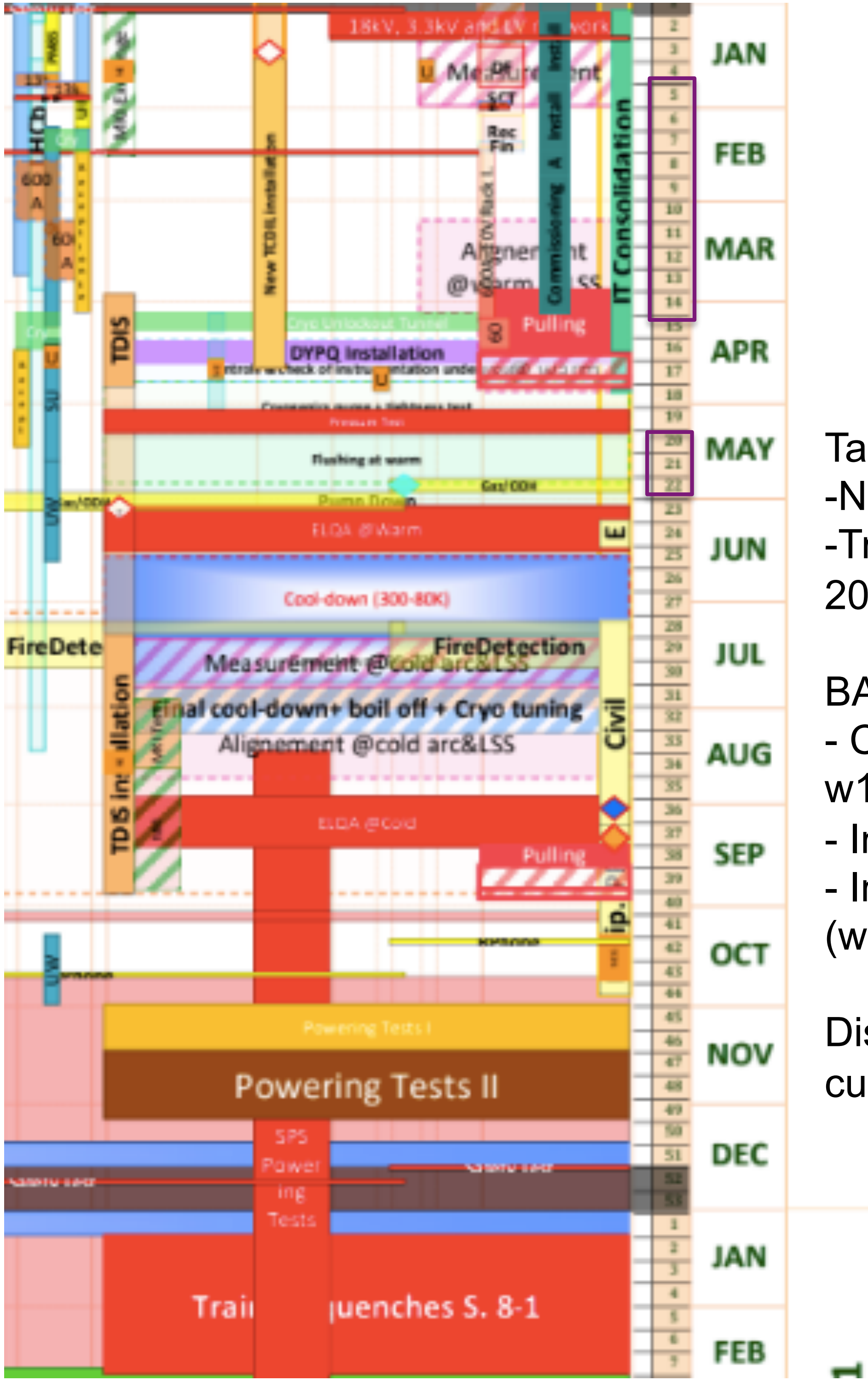
Akitaki Ariga,[1] Tomoko Ariga,[1,2] Jamie Boyd,[3] Franck Cadoux,[4] David W. Casper,[5] Yannick Favre,[4] Jonathan L. Feng,[5] Didier Ferrere,[4] Iftah Galon,[6] Sergio Gonzalez-Sevilla,[4] Shih-Chieh Hsu,[7] Giuseppe Iacobucci,[4] Enrique Kajomovitz,[8] Felix Kling,[5] Susanne Kuehn,[3] Lorne Levinson,[9] Hidetoshi Otono,[2] Brian Petersen,[3] Osamu Sato,[10] Matthias Schott,[11] Anna Sfyrla,[4] Jordan Smolinsky,[5] Aaron M. Soffa,[5] Yosuke Takubo,[12] Eric Torrence,[13] Sebastian Trojanowski,[14,15] and Gang Zhang[16]

ACKNOWLEDGEMENTS

The FASER Collaboration gratefully acknowledges the contributions of many people

We are grateful to the ATLAS SCT project and the LHCb Calorimeter project for letting us use spare modules as part of the FASER experiment. In addition, FASER gratefully acknowledges invaluable assistance from many people, including the CERN Physics Beyond Colliders study group; the LHC Tunnel Region Experiment (TREX) working group; Rhodri Jones, James Storey, Swann Levasseur, Christos Zamantzas, Tom Levens, Enrico Bravin (beam instrumentation); Dominique Missiaen, Pierre Valentin, Tobias Dobers (survey); Jonathan Gall, John Osborne (civil engineering); Caterina Bertone, Serge Pelletier, Frederic Delsaux (transport); Francesco Cerutti, Marta Sabaté-Gilarte, Andrea Tsinganis (FLUKA simulation and background characterization);Pierre Thonet, Attilio Milanese, Davide Tommasini, Luca Bottura (magnets); Burkhard Schmitt, Christian Joram, Raphael Dumps, Sune Jacobsen (scintillators); Dave Robinson, Steve McMahon (ATLAS SCT); Yuri Guz (LHCb calorimeters); Salvatore Danzeca (Radiation Monitoring);Stephane Fartoukh, Jorg Wenninger (LHC optics), Michaela Schaumann (LHC vibrations); Marzia Bernardini, Anne-Laure Perrot, Katy Foraz, Thomas Otto, Markus Brugger (LHC access and schedule); Simon Marsh, Marco Andreini, Olga Beltramello (safety); Stephen Wotton, Floris Keizer (SCT QA system and SCT readout); Liam Dougherty (integration);Yannic Body, Olivier Crespo-Lopez (cooling/ventilation); Yann Maurer (power); Marc Collignon, Mohssen Souayah (networking); Gianluca Canale, Jeremy Blanc, Maria Papamichali (readout signals); Bernd Panzer-Steindel (computing infrastructure); and Mike Lamont, Fido Dittus, Andreas Hoecker, Andy Lankford, Ludovico Pontecorvo, Michel Raymond, Christoph Rembser, Stefan Schlenker (useful discussions).

BACK UP



Scheduling ideas

Taking into account schedule constraints:
-No CE works in 2019 (DISMAC)
-Transport into TI12 before sector-81 is cold (mid-June 2020)

BASELINE SCHEDULE:
- CE work w5-w10, and outside working hours w11-w14
- Installation of heavy components w20/21/22
- Integration and commissioning in situ after cool down (w28), with some weeks excluded for various tests

Discussed with LS2 planning responsible, and fits in current LS2 schedule.

25

FASER LHCC DOCUMENTS

Version: 14:25 (GMT) on Wednesday 7th November, 2018
DRAFT: LHCC, 7 November 2018

TECHNICAL PROPOSAL

FASER

FORWARD SEARCH EXPERIMENT AT THE LHC

Akitaki Ariga,[1] Tomoko Ariga,[1,2] Jamie Boyd,[3,*] Franck Cadoux,[4] David W. Casper,[5] Francesco Cerutti,[3] Salvatore Danzeca,[3] Liam Dougherty,[3] Yannick Favre,[4] Jonathan L. Feng,[5,†] Didier Ferrere,[4] Jonathan Gall,[3] Iftah Galon,[6] Sergio Gonzalez-Sevilla,[4] Shih-Chieh Hsu,[7] Giuseppe Iacobucci,[4] Enrique Kajomovitz,[8] Felix Kling,[5] Susanne Kuehn,[3] Mike Lamont,[3] Lorne Levinson,[9] Hidetoshi Otono,[2] John Osborne,[3] Brian Petersen,[3] Osamu Sato,[10] Marta Sabaté-Gilarte,[3,11] Matthias Schott,[12] Anna Sfyrla,[4] Jordan Smolinsky,[5] Aaron M. Soffa,[5] Yosuke Takubo,[13] Pierre Thonet,[3] Eric Torrence,[14] Sebastian Trojanowski,[15] and Gang Zhang[16]

[1] *Universität Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland*
[2] *Kyushu University, Nishi-ku, 819-0395 Fukuoka, Japan*
[3] *CERN, CH-1211 Geneva 23, Switzerland*
[4] *University of Geneva, CH-1211 Geneva 4, Switzerland*
[5] *University of California, Irvine, CA 92697-4575, USA*
[6] *Rutgers, Piscataway, New Jersey 08854-8019, USA*
[7] *University of Washington, PO Box 351560, Seattle, WA 98195-1560, USA*
[8] *Technion—Israel Institute of Technology, Haifa 32000, Israel*
[9] *Weizmann Institute of Science, Rehovot 761001, Israel*
[10] *Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8602, Japan*
[11] *University of Seville, Seville, Spain*
[12] *Institut fr Physik, Universitt Mainz, Mainz, Germany*
[13] *KEK, Oho 1-1, Tsukuba, Ibaraki 305-0801, Japan*
[14] *University of Oregon, Eugene, OR 97403, USA*
[15] *University of Sheffield, Sheffield, S3 7RH, UK*
[16] *Tsinghua University, Beijing, China*

1

Submitted to the LHCC, 18 July 2018

CERN-LHCC-2018-030, LHCC-I-032
UCI-TR-2018-18, KYUSHU-RCAPP-2018-05

LETTER OF INTENT

FASER

FORWARD SEARCH EXPERIMENT AT THE LHC

Akitaka Ariga,[1] Tomoko Ariga,[1,2] Jamie Boyd,[3,*] David W. Casper,[4] Jonathan L. Feng,[4,†] Iftah Galon,[5] Shih-Chieh Hsu,[6] Felix Kling,[4] Hidetoshi Otono,[2] Brian Petersen,[3] Osamu Sato,[7] Aaron M. Soffa,[4] Jeffrey R. Swaney,[4] and Sebastian Trojanowski[8]

[1] *Universität Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland*
[2] *Kyushu University, Nishi-ku, 819-0395 Fukuoka, Japan*
[3] *CERN, CH-1211 Geneva 23, Switzerland*
[4] *Department of Physics and Astronomy, University of California, Irvine, CA 92697-4575, USA*
[5] *New High Energy Theory Center, Rutgers, The State University of New Jersey, Piscataway, New Jersey 08854-8019, USA*
[6] *University of Washington, PO Box 351560, Seattle, WA 98195-1560, USA*
[7] *Nagoya University, Furo-cho, Chikusa-ku, Nagoya-shi 464-8602, Japan*
[8] *National Centre for Nuclear Research, Hoża 69, 00-681 Warsaw, Poland*

Executive Summary

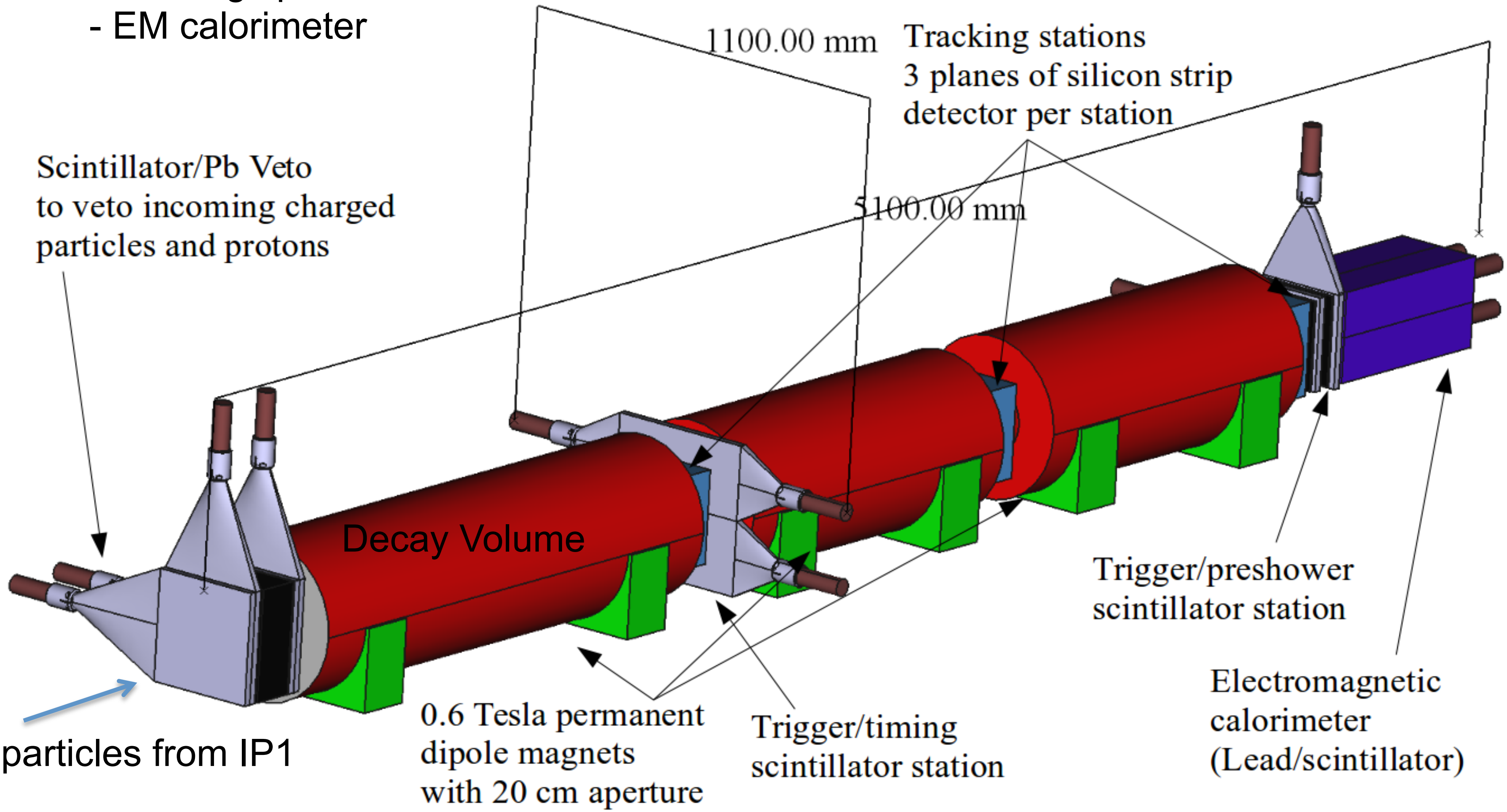
FASER is a proposed small and inexpensive experiment designed to search for light, weakly-interacting particles at the LHC. Such particles are dominantly produced along the beam collision axis and may be long-lived, traveling hundreds of meters before decaying. To exploit both of these properties, FASER is to be located along the beam collision axis, 480 m downstream from the ATLAS interaction point, in the unused service tunnel TI18. We propose that FASER be installed in TI18 in Long Shutdown 2 in time to collect data from 2021-23 during Run 3 of the 14 TeV LHC. FASER will detect new particles that decay within a cylindrical volume with radius $R = 10$ cm and length $L = 1.5$ m. With these small dimensions, FASER will complement the LHC's existing physics program, extending its discovery potential to a host of new particles, including dark photons, axion-like particles, and other CP-odd scalars. A FLUKA simulation and analytical estimates have confirmed that numerous potential backgrounds are highly suppressed at the FASER location, and the first *in situ* measurements are currently underway. We describe FASER's location and discovery potential, its target signals and backgrounds, the detector's layout and components, and the experiment's preliminary cost estimate, funding, and timeline.

* Contact email: Jamie.Boyd@cern.ch
† Contact email: jlf@uci.edu

i

THE FASER DETECTOR

The detector consists of:
- Scintillator veto
- 1.5m long decay volume
- 2m long spectrometer
- EM calorimeter



THE FASER DETECTOR

Main components:

-3 permanent dipole magnets
- Based on Halbach array
- Preliminary design as option for NTOF (not chosen)
- 0.6T, two magnets 1m long (~1 tonne each), and one 1.5m long (~1.4 tonnes)

- Tracking stations
- Build using spare ATLAS SCT silicon strip detector modules
- Stations will need cooling, using standalone water chiller (10 degree water input)
- Stations will need dry air (to be provided by EN-CV)

- Calorimeter
- Build using 4 spare LHCb outer calorimeter modules (Pb/Scintillator) + PMT readout

- Scintillator stations
- simple scintillator planes with PMT readout

Some electronics will be placed in TI12:

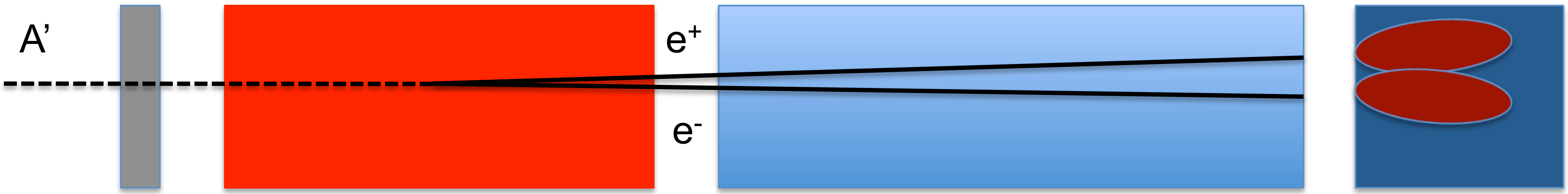
- power supplies
- tracker readout boards
- digitizer for PMT waveforms + dedicated trigger logic board
- detector control / interlock system for tracker power/cooling
- ethernet switch

THE FASER DETECTOR

The detector consists of:

- Scintillator veto
- 1.5m long decay volume
- 2m long spectrometer
- EM calorimeter

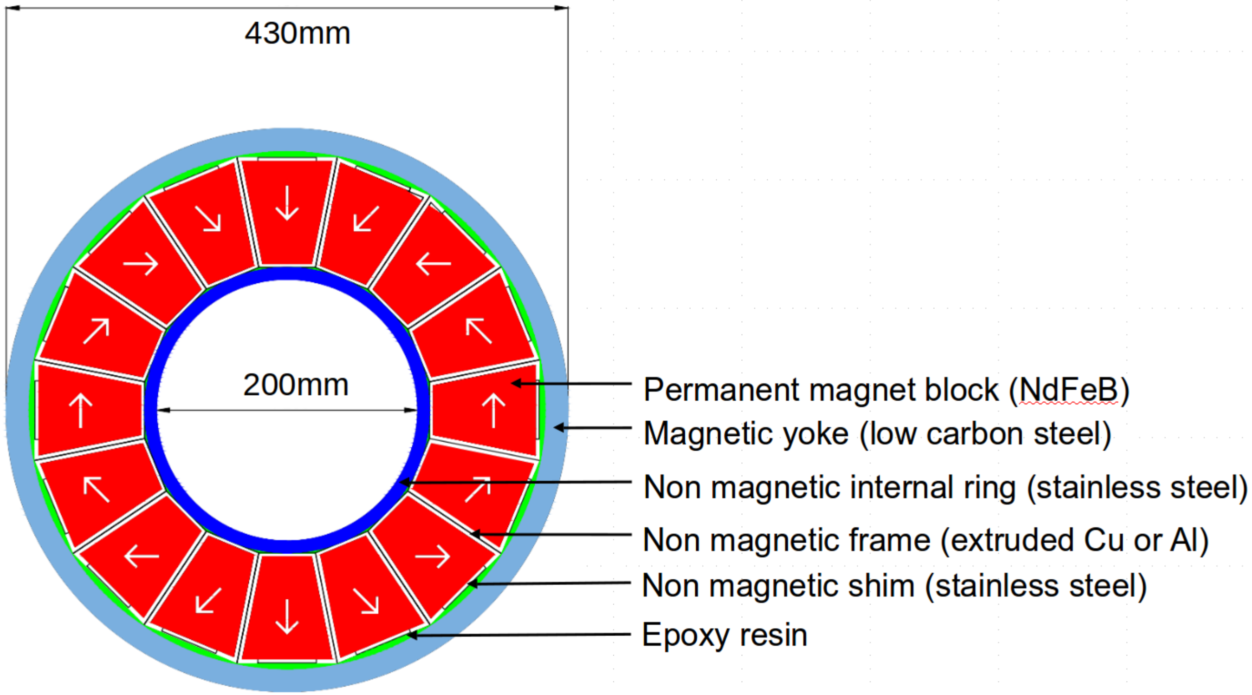
Signal signature

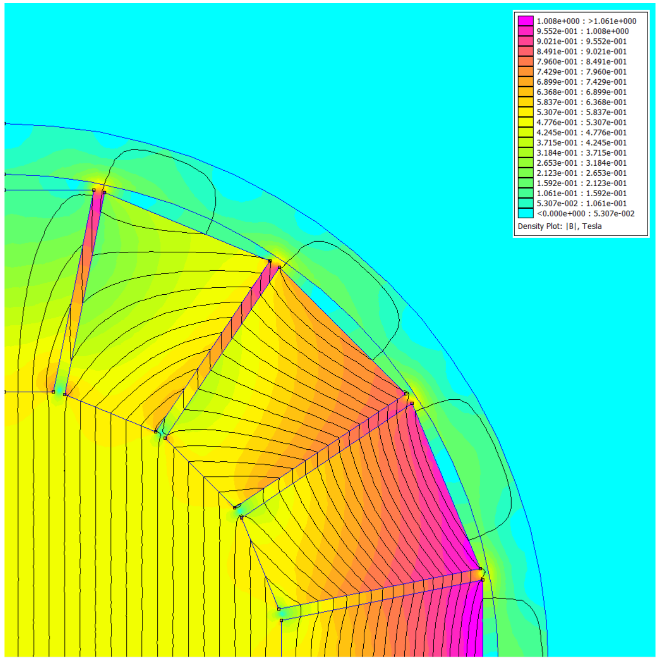


1. No signal in the veto scintillator;
2. Two high energy oppositely charged tracks, consistent with originating from a common vertex in the decay volume, and with a combined momentum pointing back to the IP;
3. For A'->ee decay: Large EM energy in calorimeter. EM showers too close to be resolved.

Magnets needed to separate the A' decay products sufficiently to be able to be resolved in tracker

FASER MAGNETS

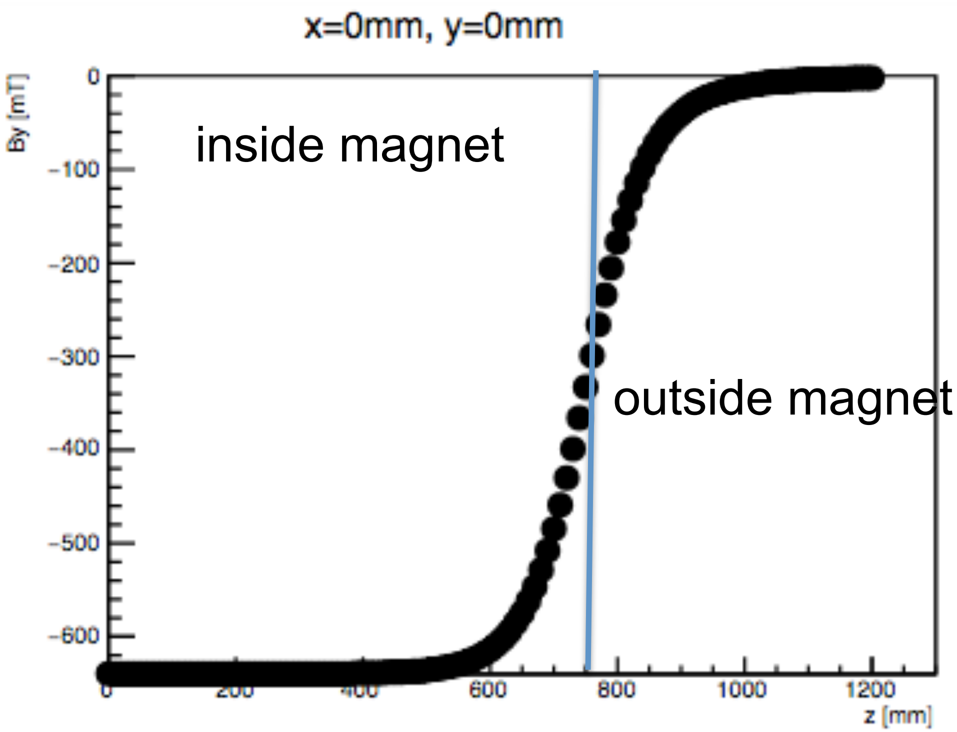




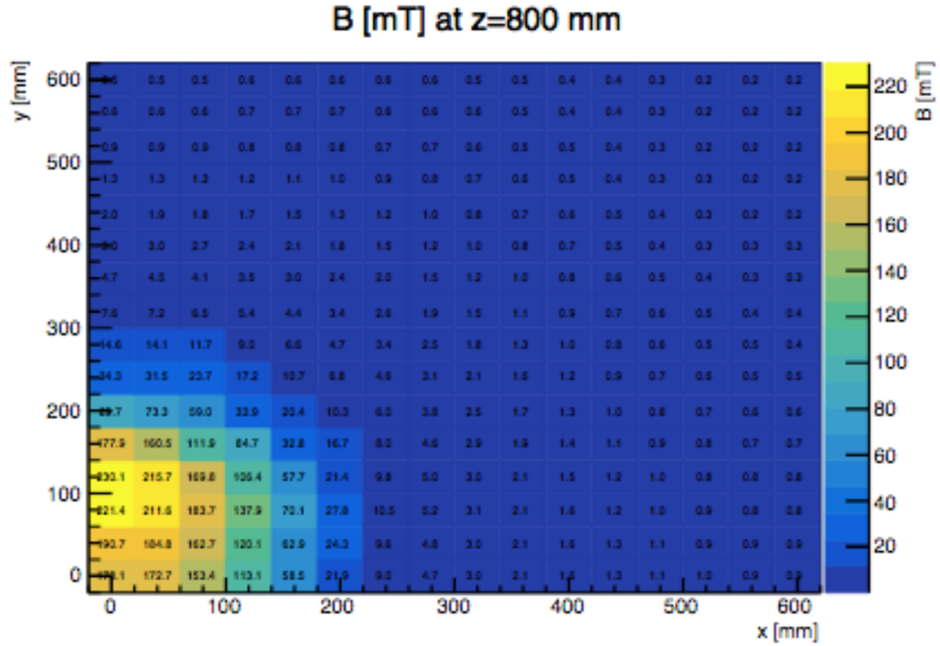
- The FASER magnets are 0.6T permanent dipole magnets based on the Halbach array design
  - Thin enough to allow the LOS to pass through the magnet center with minimum digging to the floor in TI12
  - Minimized needed services (power, cooling etc..)
- To be constructed by the CERN magnet group

STRAY MAGNETIC FIELD

- More detailed calculation of stray field, also going to larger distance
  - 3mT limit (for signage at CERN) always within 50cm of magnet centre (so enclosed in trench, does not impact access)



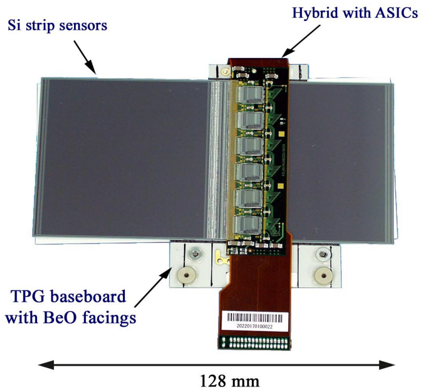
5cm outside magnet opening



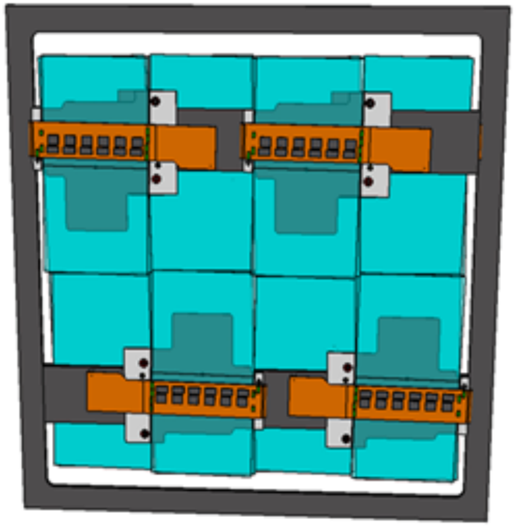
1mT field 50cm from magnet centre

FASER TRACKER

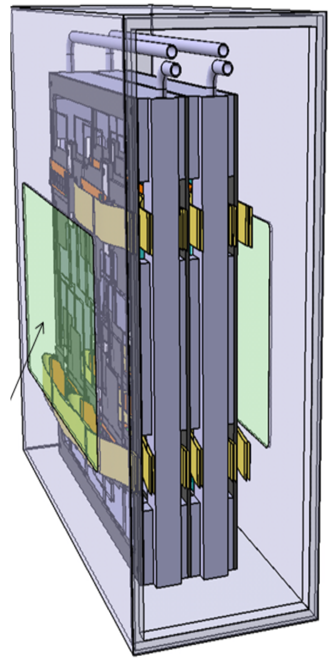
- The FASER Tracker will be made up of 3 tracking stations
- Each containing 3 layers of double sided silicon micro-strip detectors
  - Spare ATLAS SCT modules will be used
    - 80µm strip pitch, 40mrad stereo angle
    - Many thanks to the ATLAS SCT collaboration!
- 8 SCT modules give a 24cm x 24cm tracking layer, 72 SCT modules are needed for the full tracker (10^5 channels in total)
- Due to the low radiation in TI12 the silicon can be operated at room temperature, but the detector needs to be cooled to remove heat from the on-detector ASICs



SCT module

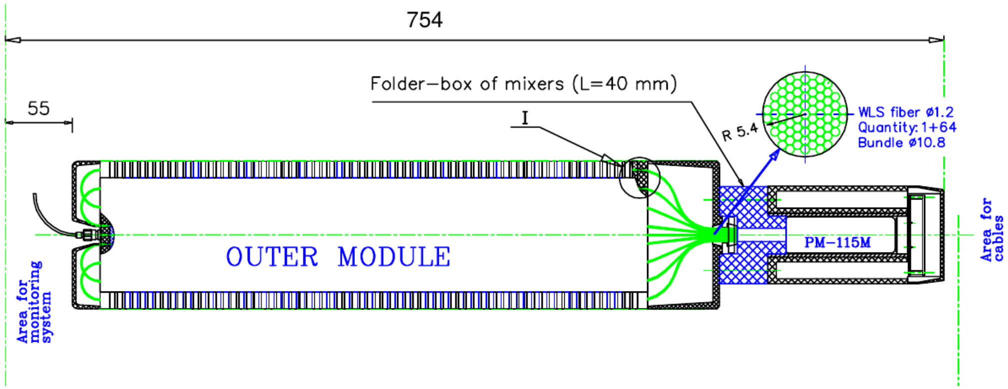


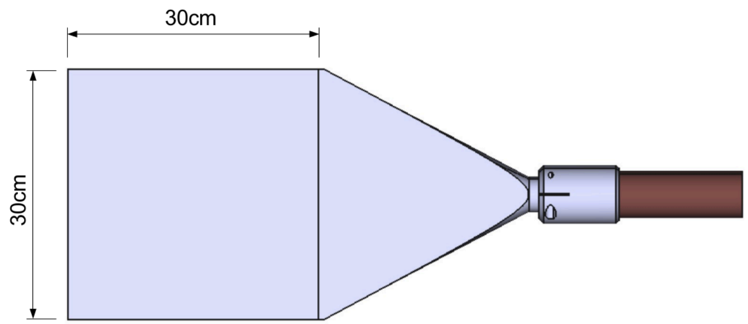
Tracking layer



Tracking station

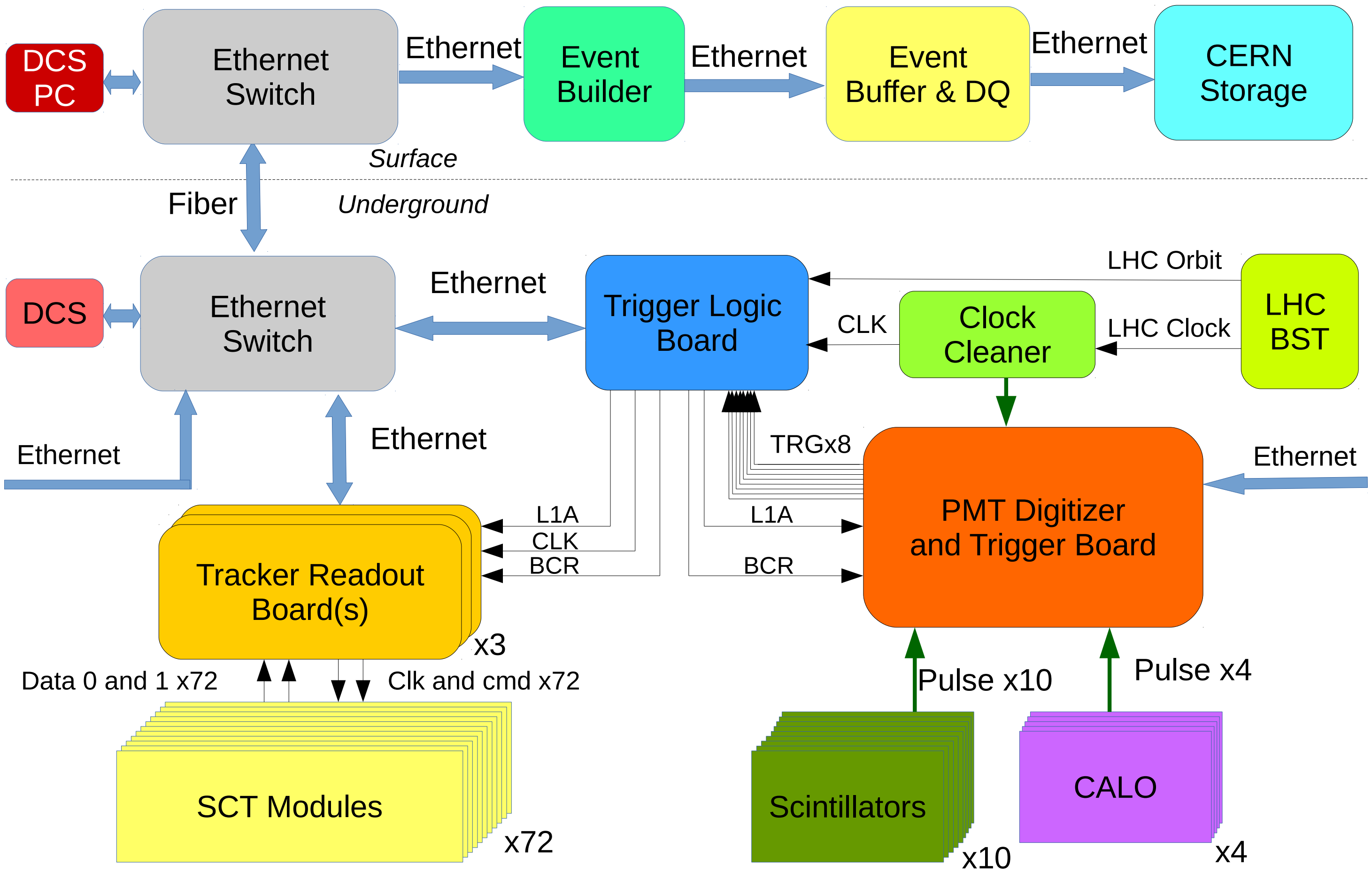
CALORIMETER / SCINTILLATORS





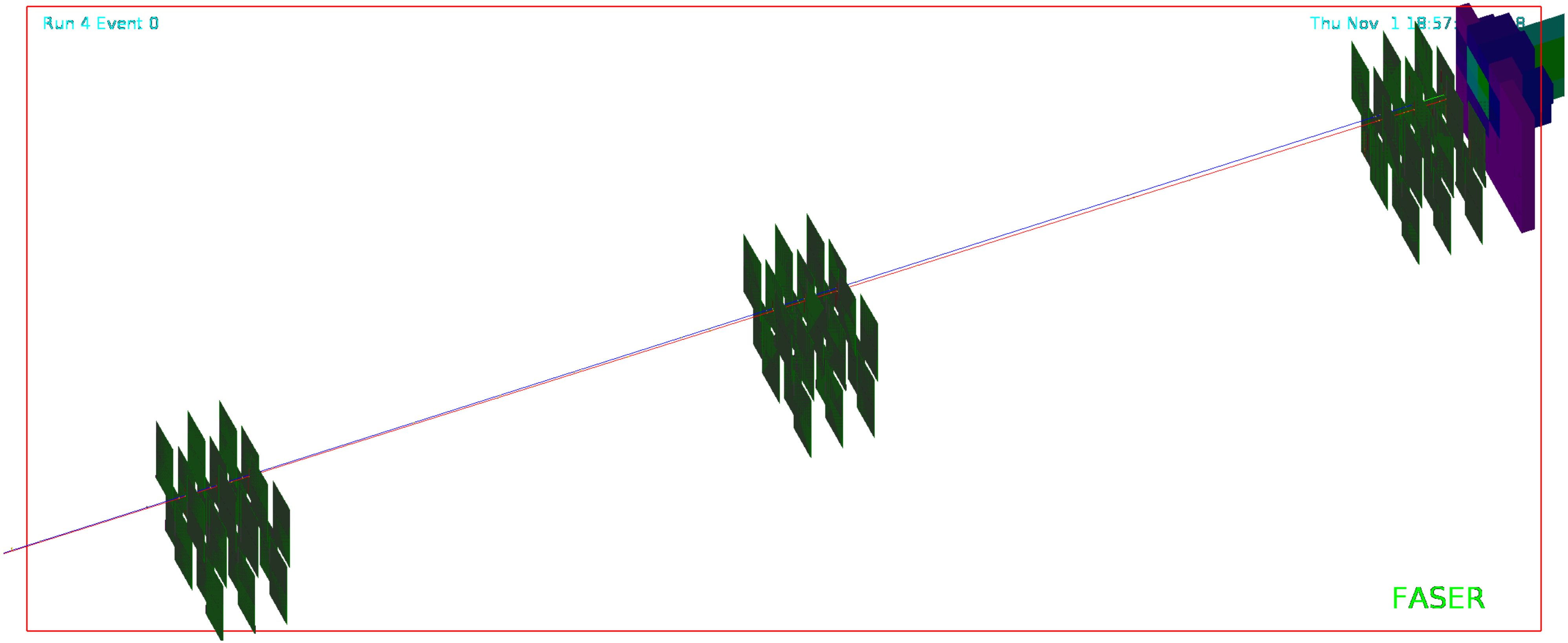
- FASER will have an ECAL for:
  - measuring the EM energy in the event
  - electron/photon identification
  - triggering
- Will use 4 spare LHCb outer ECAL modules
  - Many thanks for LHCb for allowing us to use these!
  - Provides ~1% energy resolution for 1 TeV electrons
- Scintillators used for vetoing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

TDAQ OVERVIEW



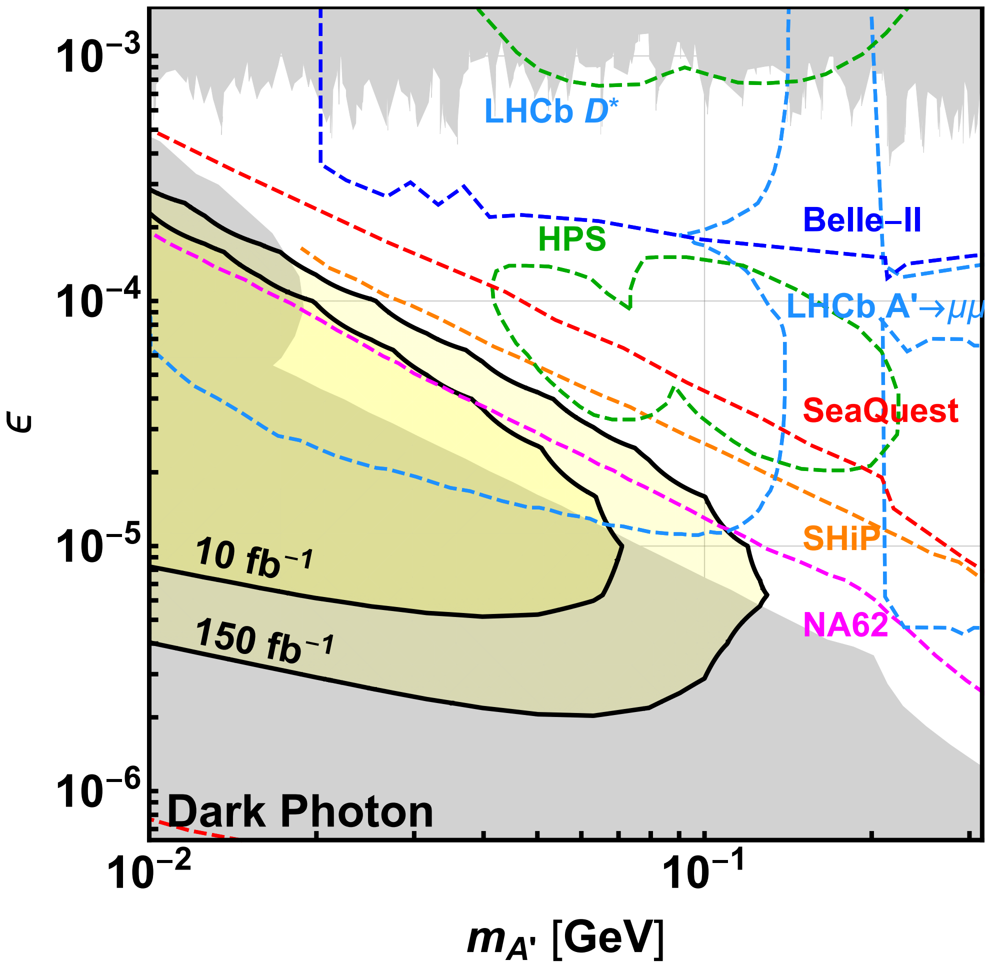
Trigger rate expected to be ~600 Hz dominated by muons from IP.
Trigger will be an OR of triggers from scintillators and from the ECAL.
No signals shared with ATLAS, need LHC orbit and clock signals, and for offline analysis ATLAS luminosity.

SIGNAL EVENT



EXPECTED SENSITIVITY

- Sensitivity for dark photons
  - Assuming no background and 100% signal efficiency (changing this does not have a big effect)
  - Curves only slightly effected by O(1) changes in efficiency



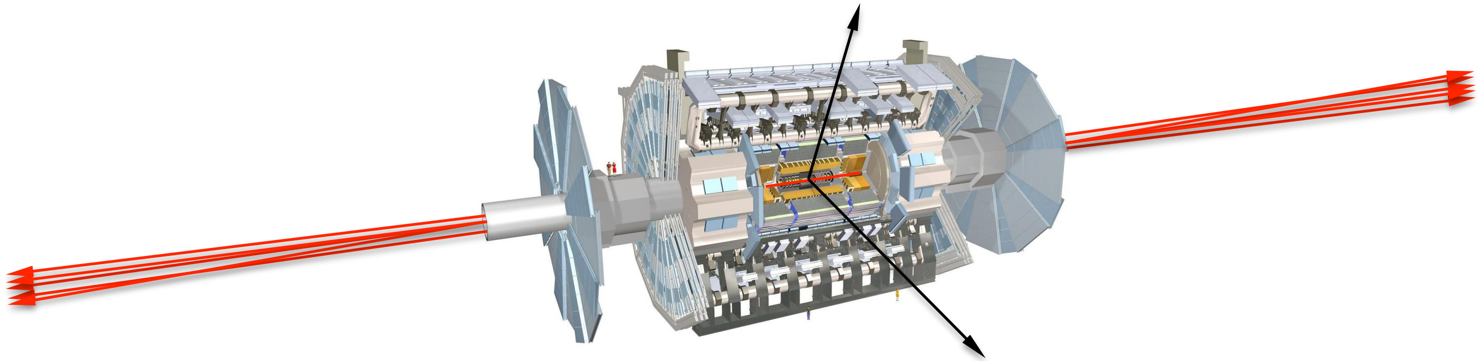
Even with 10/fb (to be collected by end of 2021?) have sensitivity to uncharted territory.
With full Run 3 dataset (150/fb) significant discovery potential.

arXiv:1708.09389

FASER: THE IDEA

- New physics searches at the LHC focus on high p_T. This is appropriate for heavy, strongly interacting particles
  - σ ~ fb to pb → In Run-3 N ~ 10^2 – 10^5, produced ~isotropically

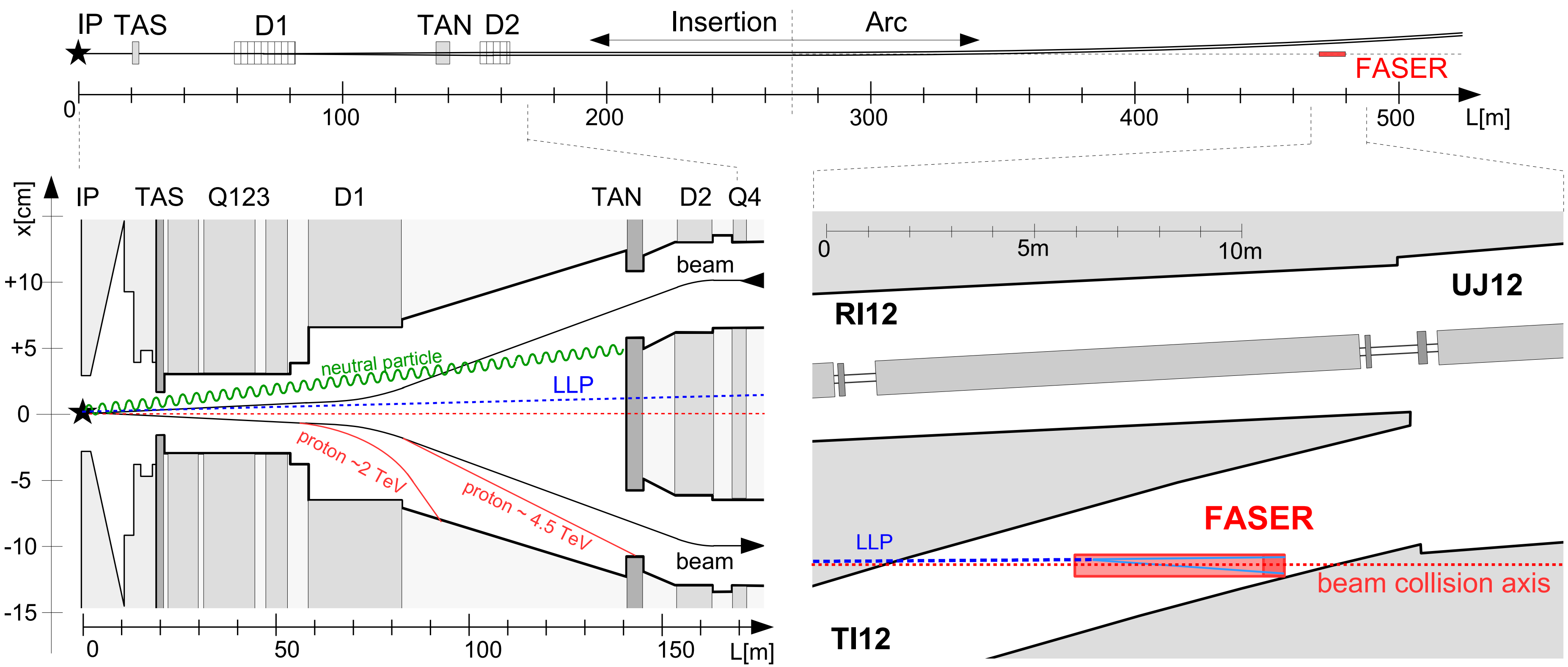
- However, if new particles are light and weakly interacting, this may be completely misguided. Instead can exploit
  - σ_{inel} ~ 100 mb → In Run-3 N ~ 10^{16}, $\theta \sim \Lambda_{QCD} / E$ ~ 250 MeV / TeV ~ mrad



- FASER is a proposed experiment designed to cover this scenario at the LHC
- Detector to be placed 480m from IP1 directly on the beam collision axis line of sight (LOS) with transverse radius of only 10cm covering the mrad regime

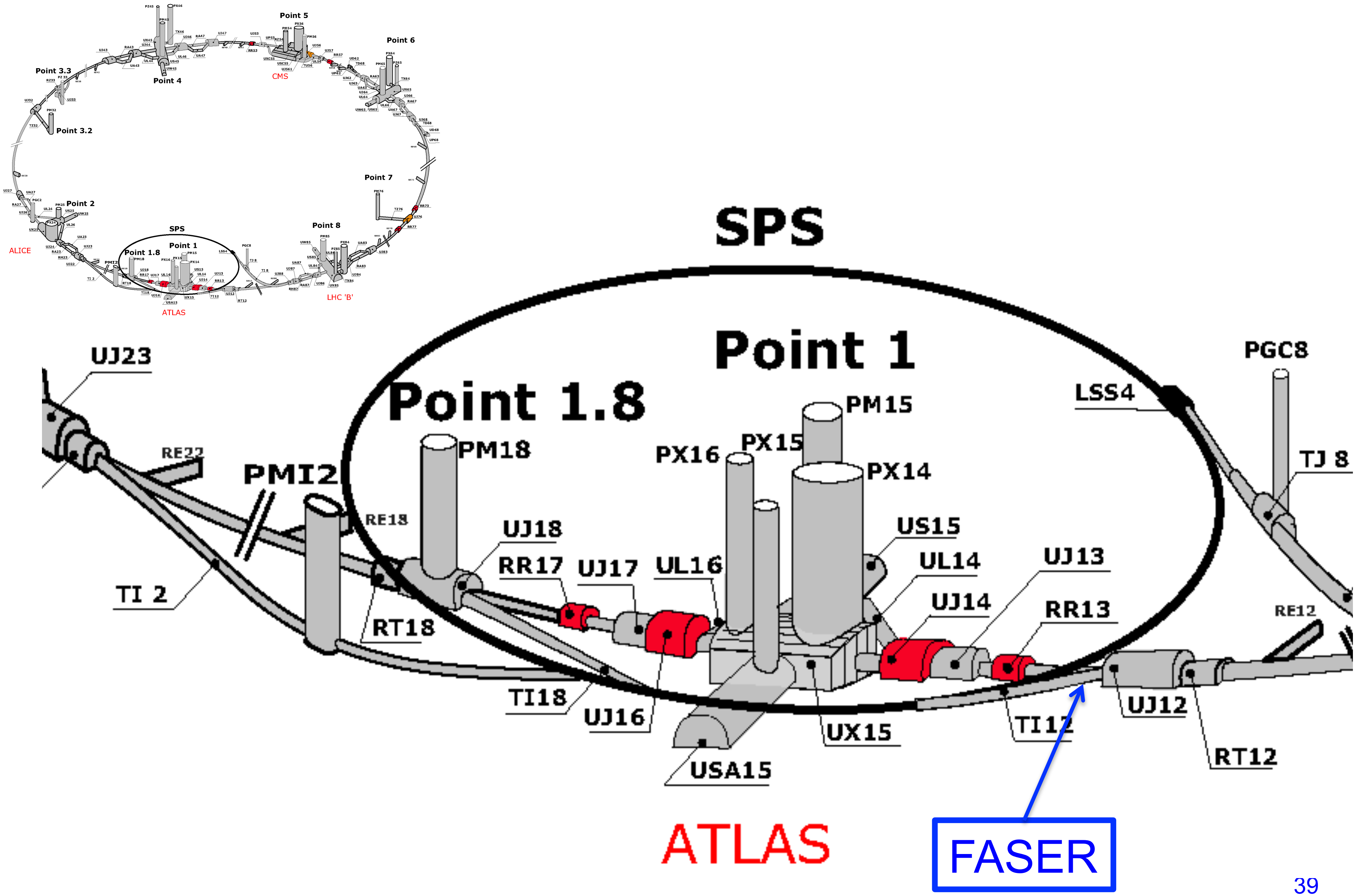
FASER LOCATION

- FASER will be situated along the beam *collision* axis line of sight (LOS)
  - ~480 m from IP
  - after beams start to bend
  - a few meters from the LHC beamline



TI12 unused tunnel, that intersects LOS 480m from IP1

FASER LOCATION: TI12



FASER WORK SO FAR

- FASER proposal has been studied in context of physics beyond colliders study group and discussed in TREX
  - Many thanks to all teams for their work on studies
- Main work so far:
  - Characterization of backgrounds/radiation in TI12
    - FLUKA studies (STI-BMI), in situ measurements:
      - BatMon (SMM-RME), emulsion and TimePix BLM (BI)
  - Planning of civil engineering works (SE-FAS)
    - including marking of LOS (SMM-ASG)
  - Detector design (FASER collaboration) + Magnet Design (MSC-MNC)
  - Integration studies (ACE-INT)
  - Transport studies (HE-PO)
  - Safety Aspects (HSE)
- Huge ***thanks*** to everyone who has contributed to FASER studies
- Studies indicate we can construct and installation of FASER in LS2, to take physics data in Run-3
- Funding for detector construction/operation secured from 2 private foundations!

HEISING-SIMONS FOUNDATION

SIMONS FOUNDATION

EFFECT OF LHC CONFIGURATION

OPTICS

• Since FASER is looking for the decay of neutral particles produced at the IP, changes in magnetic fields close to the IP (optics) do not effect the signal. In theory this could effect the background rates, but is very unlikely, and anyway such a change should not effect FASER physics.

• The beam divergence will smear out the collision products around the LOS on an event-by-event basis. Using typical expected values for Run-3 this is ~30urad corresponding to a ~1.5cm cone around the LOS – this will not effect FASER physics, although we will include it in our signal simulations.

• The crossing angle will shift the LOS compared to the nominal, this can effect FASER – see next slide.

• FASER relies on low activation in cell 12, due to dispersion function there, assume that this will not change during Run-3 (or HL-LHC for possible future experiments))

BUNCH STRUCTURE

• Since any potential signal and background rates are MUCH smaller than the bunch crossing rate (background rate ~500Hz cf 40MHz), pileup is not important. This means changes to the bunch structure will not effect FASER (for the same luminosity).

• Of course maximizing the delivered luminosity to IP1 is good for FASER physics!

FASER will not interrupt LHC running except for matters of detector/person safety. When needed we will take advantage of planned accesses.

EFFECT OF LHC CROSSING ANGLE

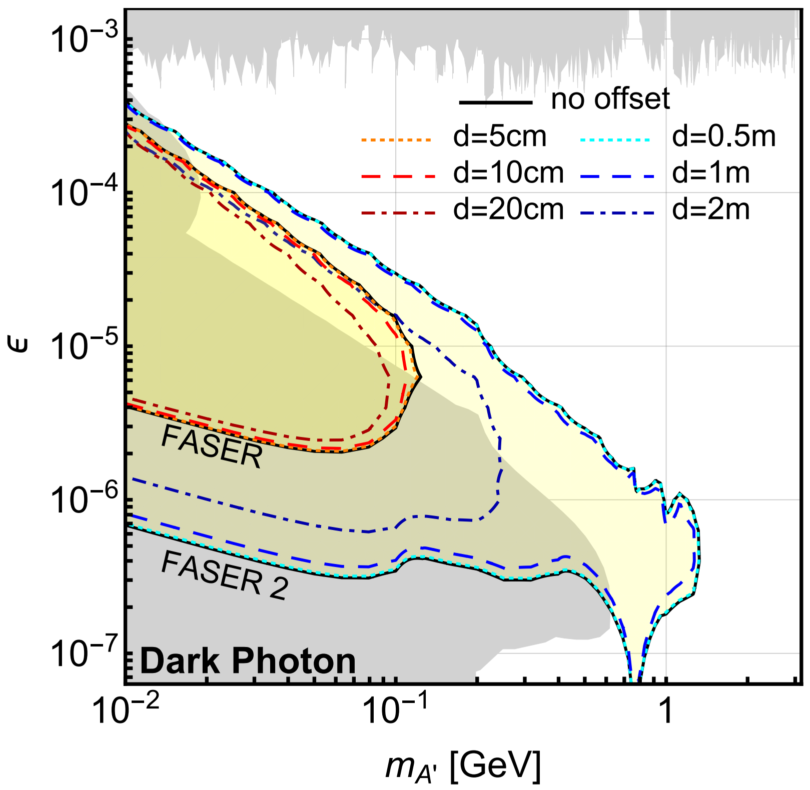
Crossing angle in ATLAS shifts the line of sight at FASER by ~7.5cm compared to the nominal (for 150 urad ½ crossing)

Discussing with Stephane Fartoukh options for crossing angle at IP1 in Run-3 are:

i) Round beams: crossing angle vertical, but sign changing every year.

ii) Flat beams: crossing angle horizontal – fixed sign for Run-3.

In all cases maximum magnitude of crossing angle expected to be similar (<170urad). Depending on β* levelling xing angle will increase/decrease as fill evolves.

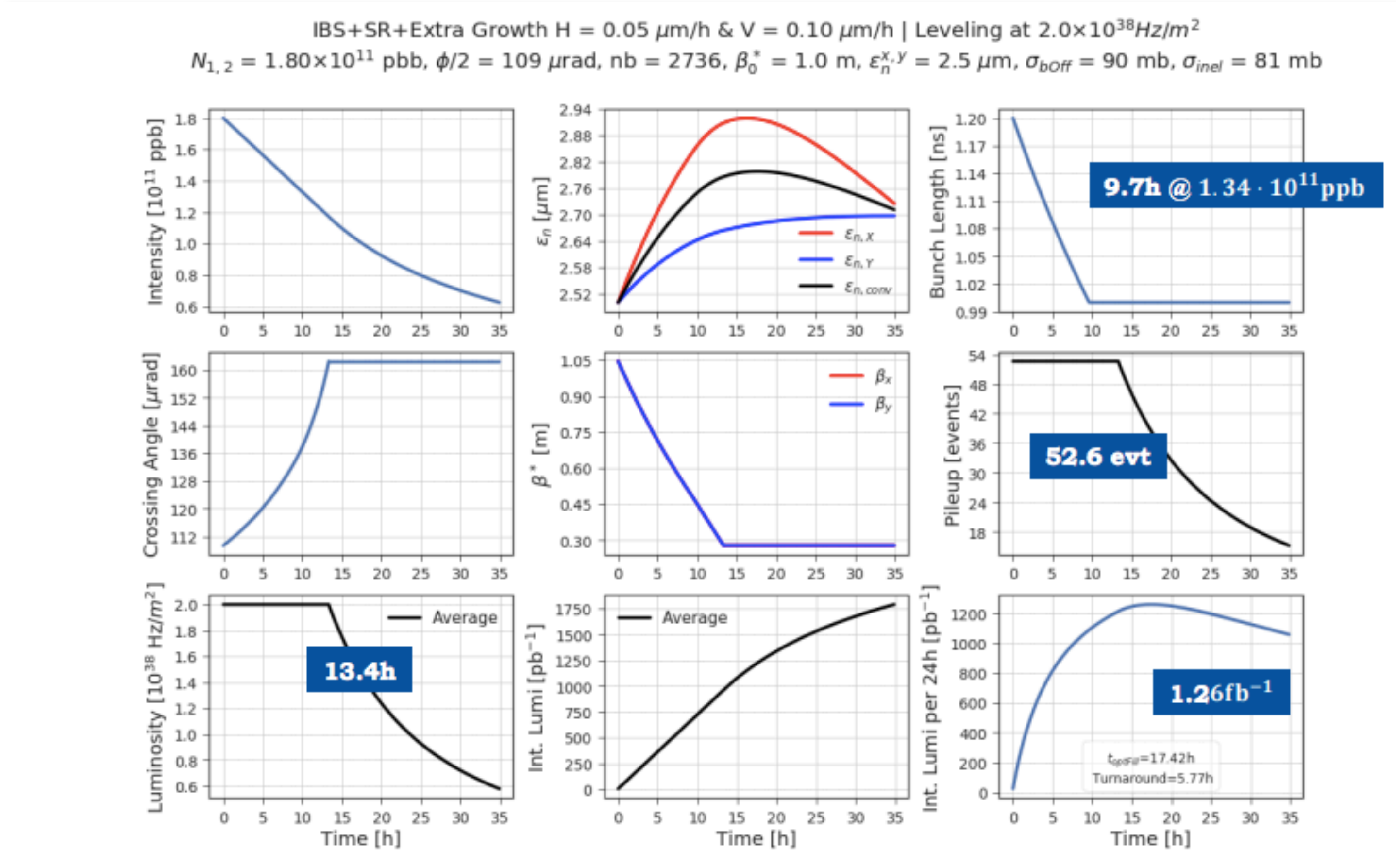


Simulation studies show that a shift of 7.5cm between the centre of the detector and the LOS leads to a reduction of 25% in signal acceptance, and a very small loss in physics sensitivity. (Larger shifts become problematic though).

Currently plan to centre detector on the nominal LOS, and live with acceptance loss. However may try to centre detector on shifted LOS if crossing angle plans become clear in time.

EFFECT OF LHC CROSSING ANGLE

Plots below possible β* levelling scenario in Run-3 (taken from: https://indico.cern.ch/event/762853/ talk by Nikos Karastathis et al).
X-ing angle 100-110urad at start of fill, slowly increased to ~160urad during fill.

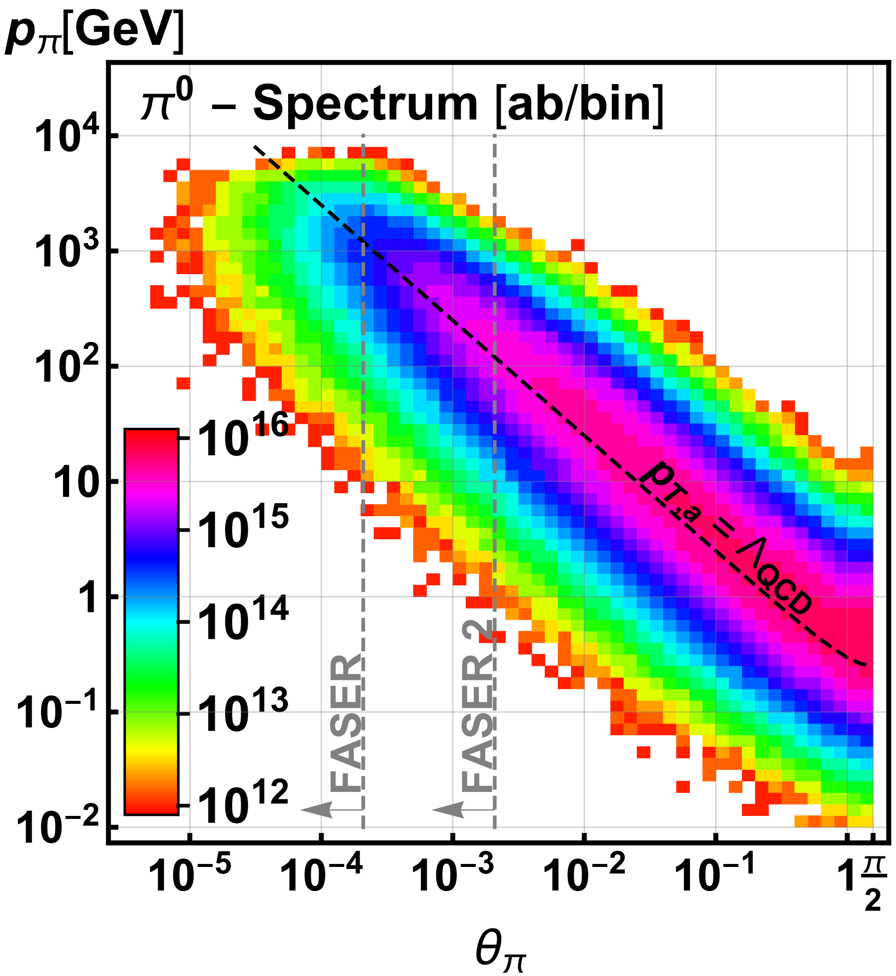


As long as x-ing angle <170urad does not effect FASER physics in a big way.

BEAM DIVERGENCE: Run-3 numbers

- Assuming a normalized emittance of 2.3um and a beam energy of 7 TeV => emittance ~3e-10m
- β*~3e-1m
- => D=30urad
- In the case of flat optics with a β* ~15cm in the vertical plane and ~60cm in the horizontal this would give:
- Dx~30/sqrt(2)urad, Dy~sqrt(2)30urad
- In Run-3 it is likely that the β* will be reduced during the fill (as is done in 2018), and the emittance also evolves as the fill progresses
  - We may want to keep track of the divergence evolution as a function of time during data taking (would need a data base to keep track of β*, and emittance in the H/V planes)

PION/DARK-PHOTON PRODUCTION AT LHC



FASER takes advantage of the the huge number of light mesons (π^0,η,..) that are produced at the LHC, predominantly in the very forward direction.

For example for E(π^0)≥ 10 GeV,

- 2% of π^0s fall in FASER acceptance;
- whereas the FASER acceptance covers just (2×10^{-6})% of the solid angle.

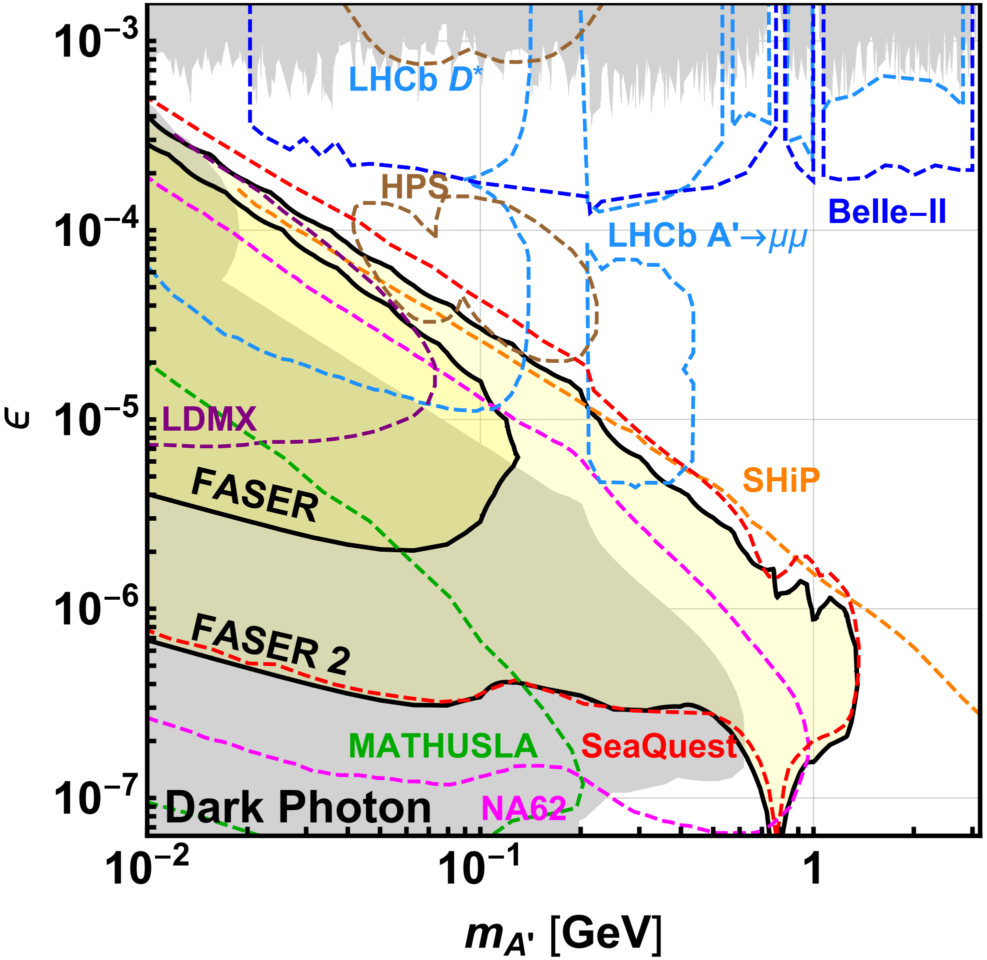
As an example: a possible new physics particle (motivated by dark matter) the "*Dark Photon*" could be produced very rarely in π^0 decays.

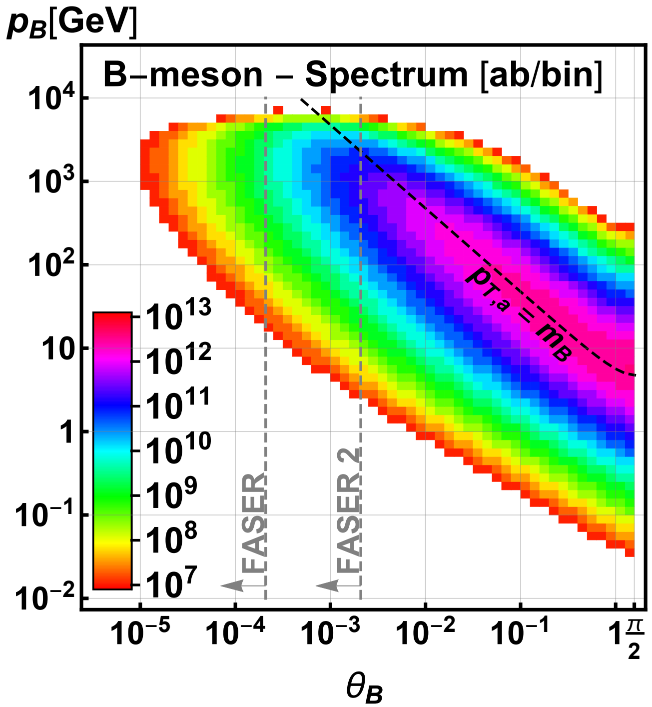
Run-3 (0.15/ab) will produce a huge number of π^0s in FASER angular acceptance. Even with large suppression (10^{-8} – 10^{-10}) can still have very large number of dark photons produced, and decaying in FASER!

LHC can be a dark photon factory!

POSSIBLE FUTURE UPGRADE - FASER 2

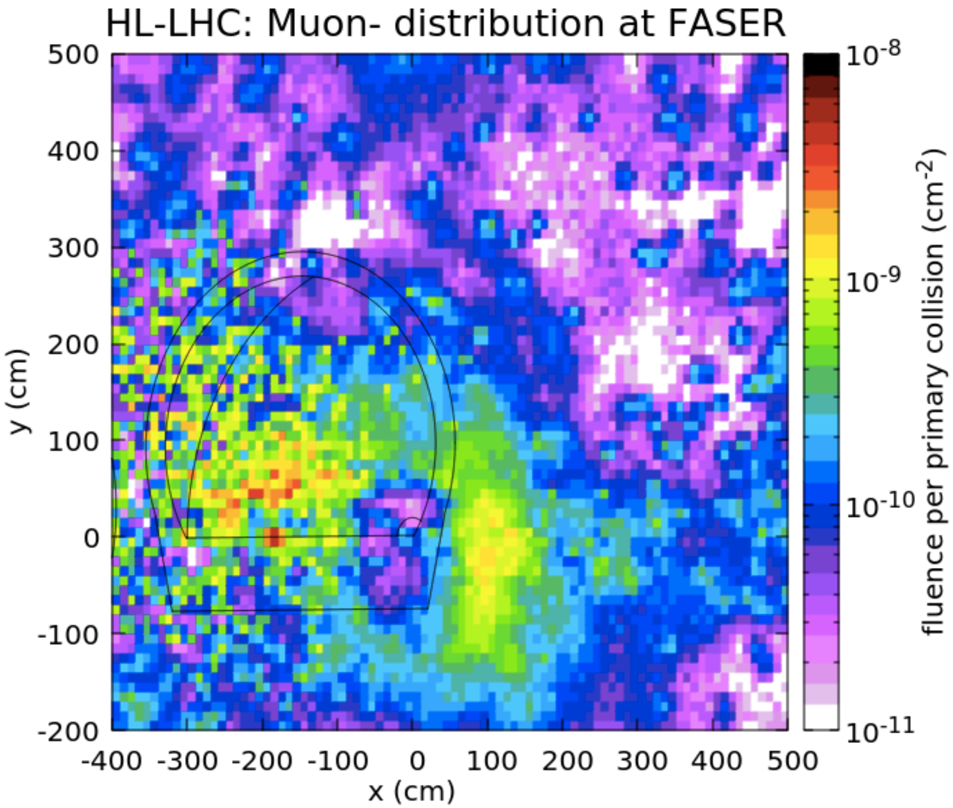
- A potential upgraded detector for HL-LHC running, would increase sensitivity further
- Increasing detector radius to 1m would allow sensitivity to new physics produced in heavy meson (B, D) decays increasing the physics case beyond just the increased luminosity

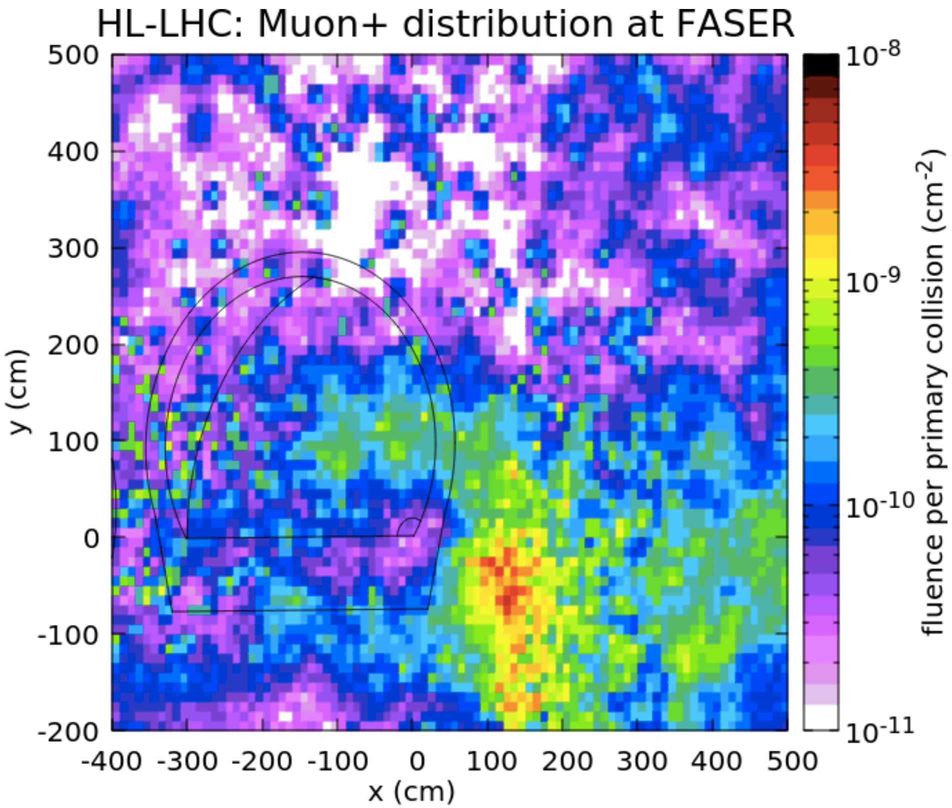




FASER and FASER 2 have sensitivity in many other models – see backup for details…

FLUKA SIMULATIONS: MUON MAP





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.

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

Expected charged particle rate for different energy thresholds ($2e34 cm^{-2}s^{-1}$)

TRANSPORT

Transport of detector components to TI12 goes via P1 (PM18 lift).
In UJ12 the components need to be carried over the LHC and QRL.
Preliminary transport study for heaviest piece (1.5m long / 1.5tonne permanent magnet). Many thanks to HE-PO team for this work.
Schedule transport before cool down of sector (mid-June 2020).
Protection to be installed over LHC/QRL in case of failure during handling.

Tooling needed for transport:

- A 2-3t hoist for the rail into UJ12 (the original ones have been removed and reinstalled on UJ62),
- Two rails into TI12 (design, production installation), and the transverse bar to make a simplified crane,
- Two 2t hoists to be installed on this rail.

CE WORKS - TIMELINE

CE works in tunnel expected to take ~6 weeks (depends on strengthening work needed).
Window in LS2 schedule when this would fit (with some contingency) in during Jan/Feb 2020.

Example schedule:

ID	Task Name	Duration
1	To Start after frozen integration design - timescales TBC	0 days
2	Civil Engineering Design	4 wks
3	**Procurement**	**90 days**
4	Produce Specification for works	4 wks
5	Procurement request with Framework lead	2 wks
6	Tender Period	4 wks
7	Tender Evaluation	4 wks
8	Tender award	0 days
9	Exchange contracts and mobilisation	4 wks
10	**Construction Works**	**35 days**
11	Works Start	0 days
12	Set up site and isolate works area	1.2 wks
13	Drilling and installation of transport fixtures	0.4 wks
14	**Modifications to existing drainage**	**21 days**
15	Saw cutting	0.4 wks
16	Remove existing drainage and make good	0.4 wks
17	Core out concrete	0.8 wks
18	Install drainage	0.8 wks
19	Pour concrete	1 day
20	**Detector Enabling Works**	**25 days**
21	Saw cutting	0.4 wks
22	Core out concrete	1.2 wks
23	Making good/ concrete base	0.4 wks
24	Clear site and demobilise	0.8 wks
25	Completion	0 days