Forward Physics Facility

PBC workshop

2/12/21

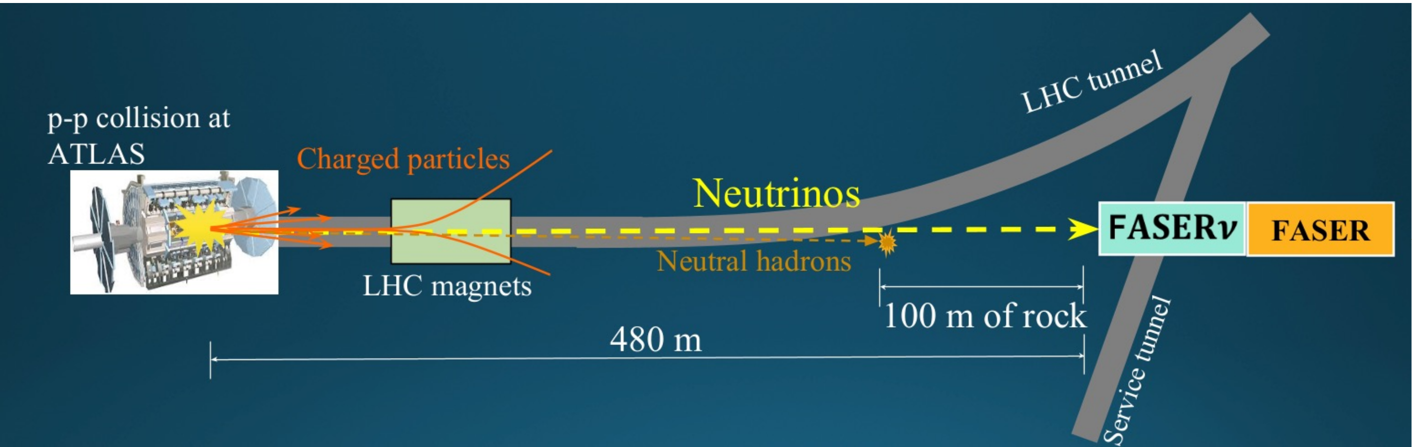
Jamie Boyd (CERN)

Overview:

- Brief introduction to the FPF
- Civil Engineering options considered
- Ongoing studies
  - RP study
  - FLUKA study
  - Sweeper magnet
- Conclusions

Introduction

- Light-weakly interacting BSM particles can be produced in the very forward region of the LHC collisions
    - Motivation for FASER experiment, situated aligned with the collision axis LOS – 480m from the collision point at IP1
- Such a location is also very interesting for neutrino experiments
    - There is a huge flux of high energy neutrinos of all flavours produced along the collision axis LOS
    - FASERnu and SND@LHC experiments are being implemented to take advantage of this in LHC Run 3
- Unfortunatly the current FASER/SND location does not have sufficient room for larger / more experiments for the HL-LHC era
    - FPF – proposed new facility to house a suite of experiments on the collision axis LOS
        - Current options either alcoves in UJ12 cavern or new cavern (~600m from IP1)



Brief Physics Motivations

- Three main physics motivations
  - BSM searches
    - Light BSM particles predominantly produced in very forward direction out of the acceptance of existing LHC experiments
      - Dark matter scattering (light dark matter particles produced in LHC collisions scattering as in a direct detection experiment)
      - Decaying dark sector particles (dark photons, dark Higgs, heavy neutral leptons…)
      - Milli-charged particles
    - See talks by M. Citron, S. Trojanowski and J.L Feng in the BSM session tomorrow
  - Neutrino physics
    - Tau neutrino studies (expect ~3k tau neutrino interactions/10tn, current world sample <20)
      - Separation of tau neutrino / anti-neutrino for first time
      - Constrain tau neutrino EDM
      - Tau neutrino -> heavy flavour (probes same diagrams as LHCb LFV anomalies!)
    - Neutrino cross section measurements (e/mu/tau), EFT constraints, neutrino + heavy flavour, ..
    - See talk by M. H. Reno this morning
  - QCD/PDFs
    - Using neutrino’s to constrain proton PDFs (intrinsic charm, strange PDF, gluon PDF at high x …)
    - Highly relevant for particle atrophysics experiments e.g. IceCube
    - See talk by M. H. Reno this morning

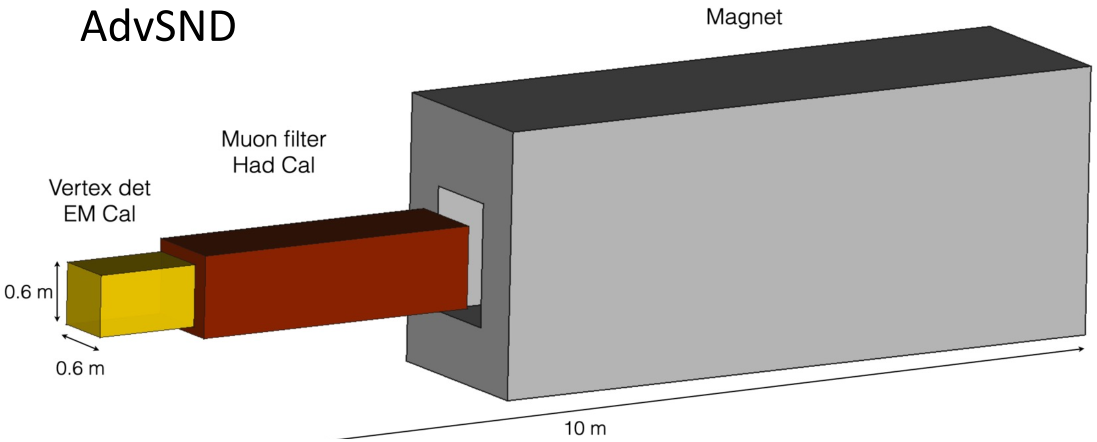
Currently proposed FPF experiments

- FLArE (LArTPC)
  - DM scattering
  - Neutrino physics (nu_e / nu_mu)
  - Sketch of design of cryo/cryostat for 20tn detector
    - Drives some of the service / safety requirements for the facility
    - LKr also being considered (see backup)
- FASERnu2
  - 10tn emulsion/tungsten detector (FASERnu x10) – mostly for tau neutrino physics
  - Interfaced to FASER2 spectrometer for muon charge ID (nu_tau / nt_tau-bar separation)
- AdvSND
  - Proposed off-axis neutrino detector (ongoing R&D on technology to use)
- FASER2
  - Similar to scaled up version of FASER (1m radius vs 0.1m)
  - Possibly with superconducting magnet
- FORMOSA
  - Milicharged particle detector (scintillator based, similar to miliQan)
  - https://arxiv.org/abs/2010.07941
  - See talk tomorrow by M. Citron

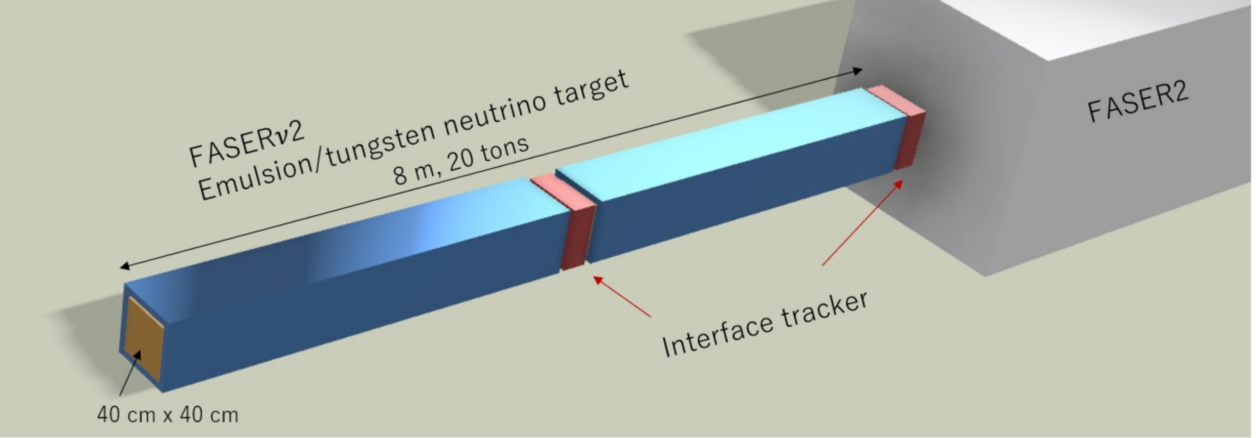
No detailed design for any of these experiments yet!

Currently proposed FPF experiments - sketches

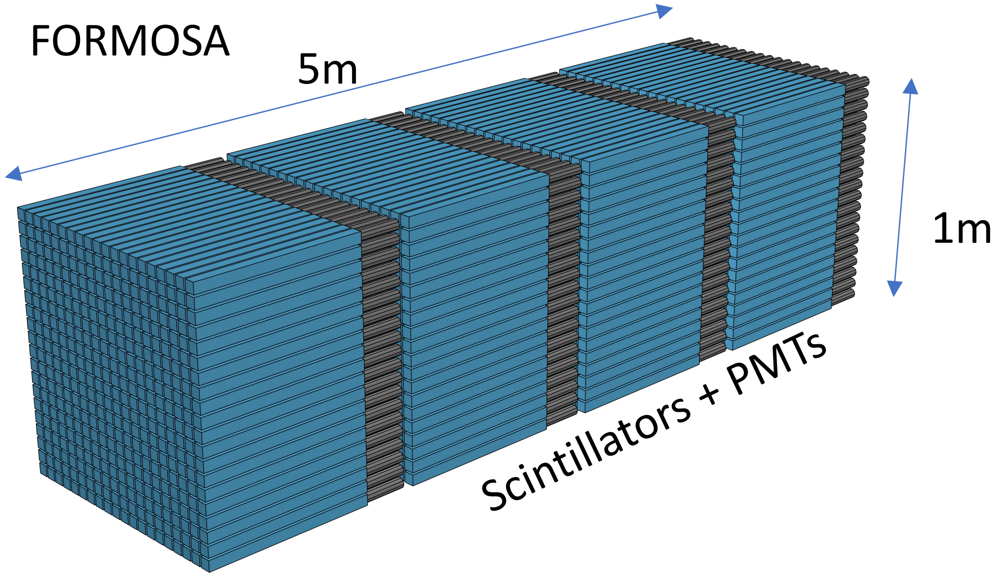
AdvSND



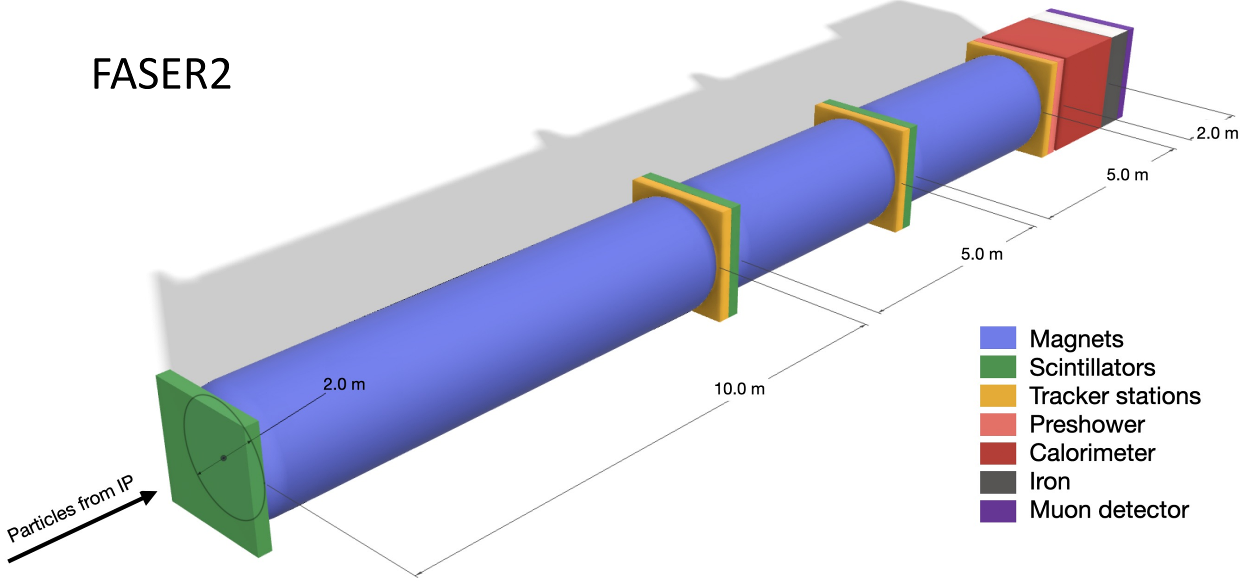
FASERnu2



FORMOSA



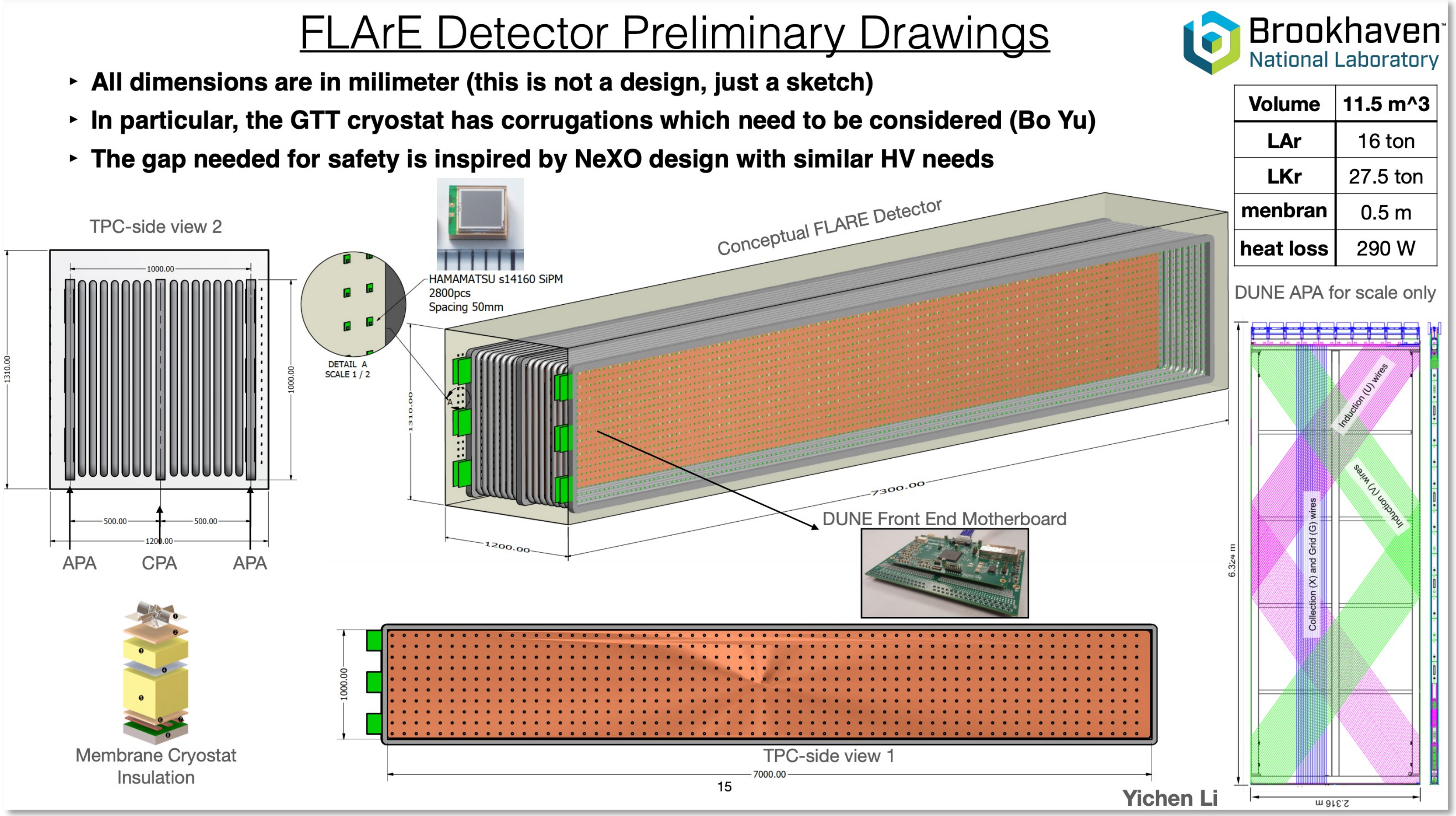
FASER2



FLArE: LAr TPC detector

Milind Diwan (BNL)
Filippo Resnati (CERN)

Proposed LAr TPC for DM scattering and neutrino physics: Order 10tonne fiducial mass under consideration.
Cryostat and cryogenics discussed with protoDune experts at CERN (see backup). Very preliminary detector concept from BNL.
Detector which needs the most novel ”design” and also probably drives the FPF services/infrastructure and safety needs!



FLArE Detector Preliminary Drawings

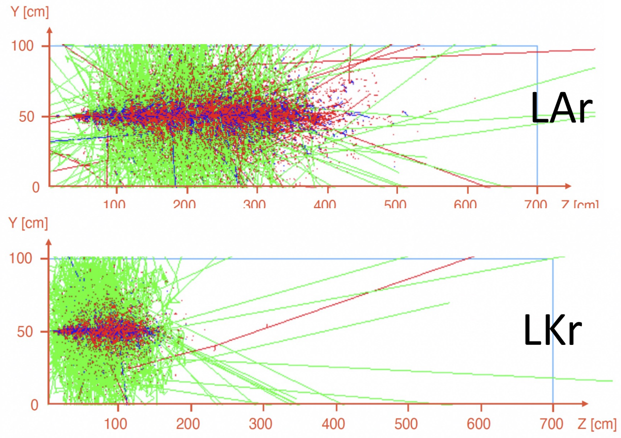
Brookhaven National Laboratory

- **All dimensions are in milimeter (this is not a design, just a sketch)**
- **In particular, the GTT cryostat has corrugations which need to be considered (Bo Yu)**
- **The gap needed for safety is inspired by NeXO design with similar HV needs**

Volume	**11.5 m^3**
LAr	16 ton
LKr	27.5 ton
membran	0.5 m
heat loss	290 W

Yichen Li

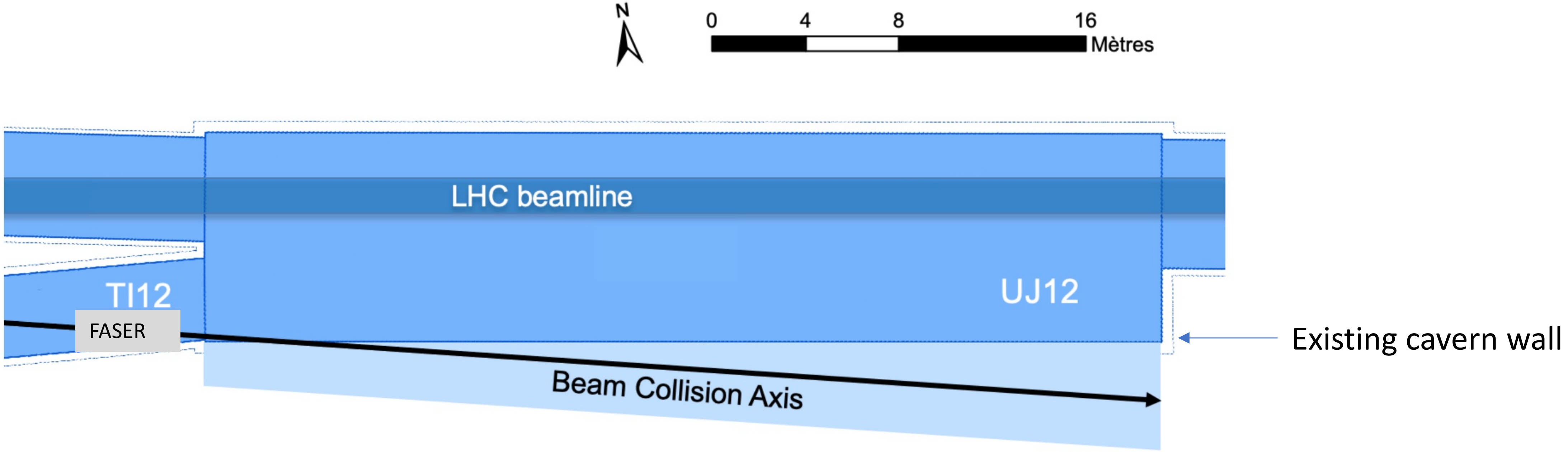
Recent development:
Considering LKr as well as LAr – better shower containment for high enregy showers.
Example from simulated 1 TeV electron shower in LAr and LKr



Wenjie Wu (UCI)

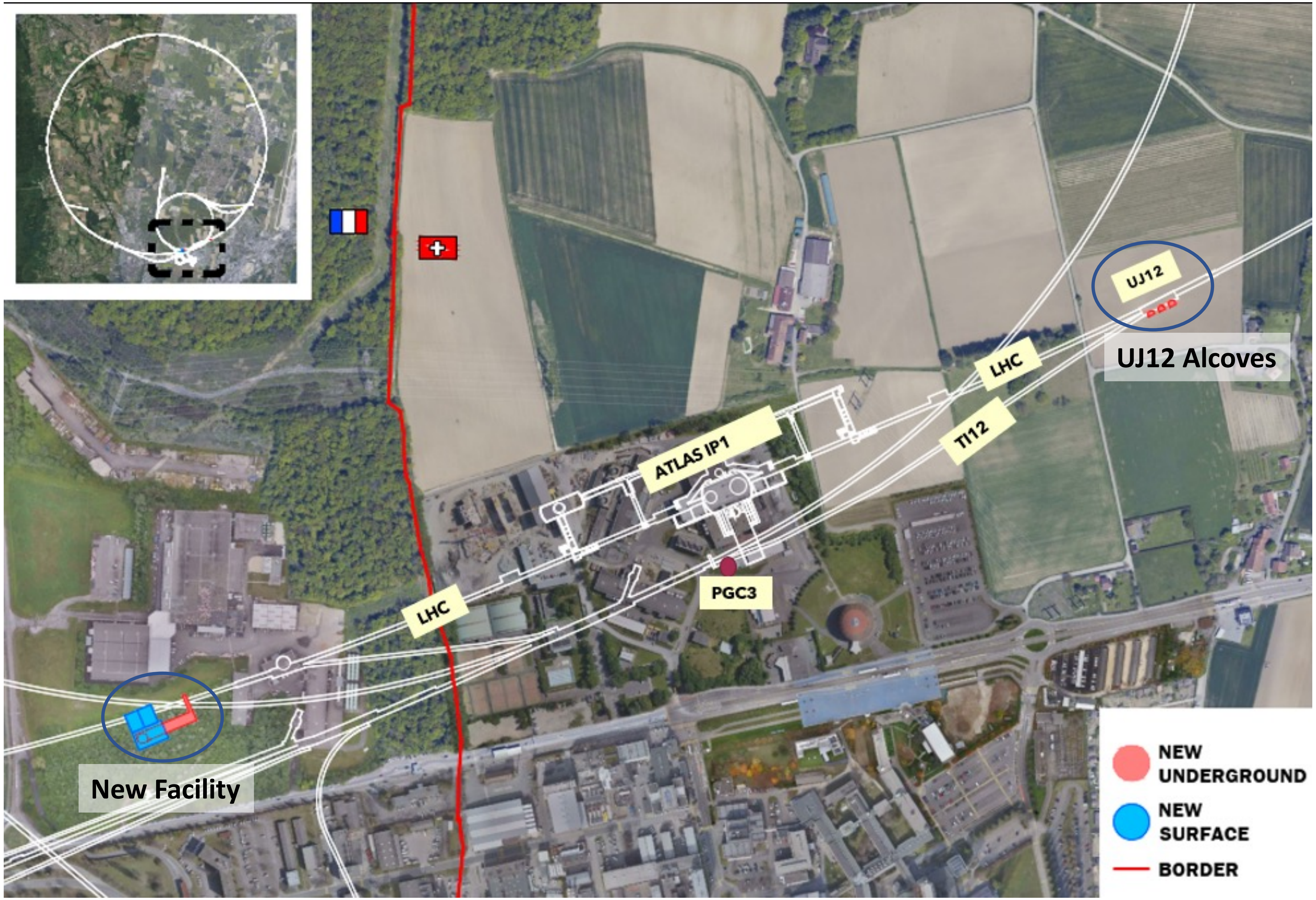
The Facility

First idea – widen UJ12 cavern to allow ~50 along the LOS



Not possible from civil engineering side.
Not possible to get sufficiently large excavation machine here, without dismantling ~500m of the LHC machine.

After several studies by civil engineering experts now concentrate on 2 options:

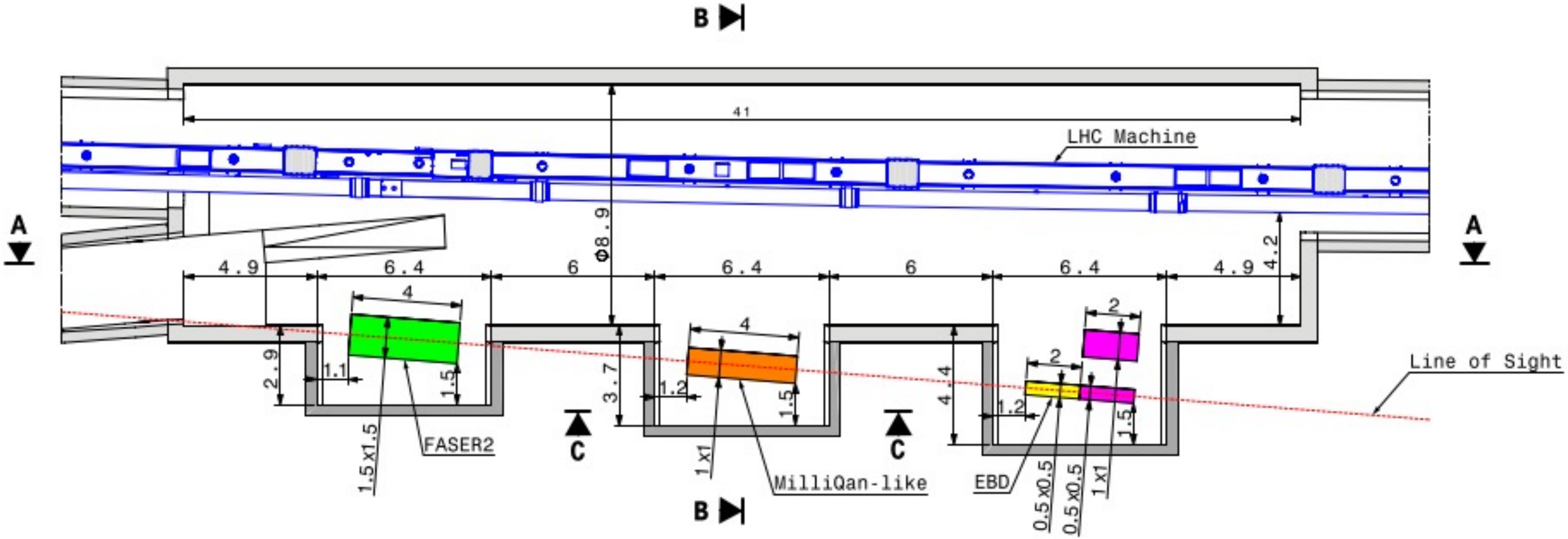


K. Balazs, J. Osborne, J. Gall - CERN SCE

UJ12 Alcoves

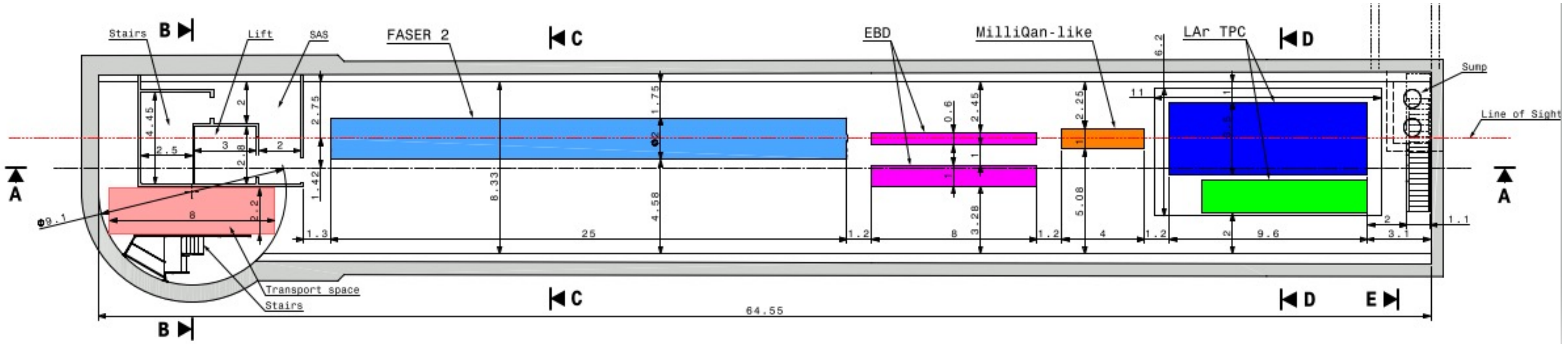
K. Balazs, J. Osborne, J. Gall - CERN SCE

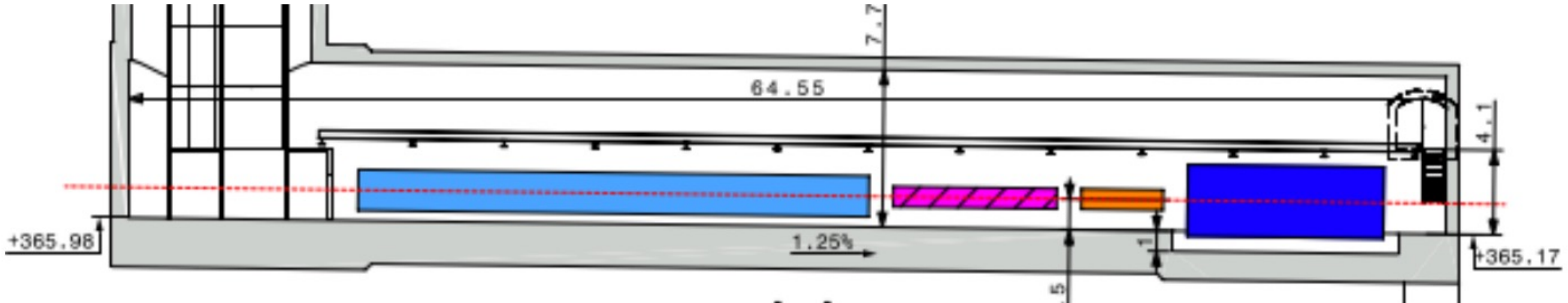
3 ‘alcoves’ in UJ12 cavern wall, would allow some more room on the LOS for experiments.
For works the full UJ12 area would need to be emptied out (LHC magnets, QRL, EN-EL/CV equipment etc…).
Seems possible but significant work.
Background / radiation from beamline may be problematic for experiments.



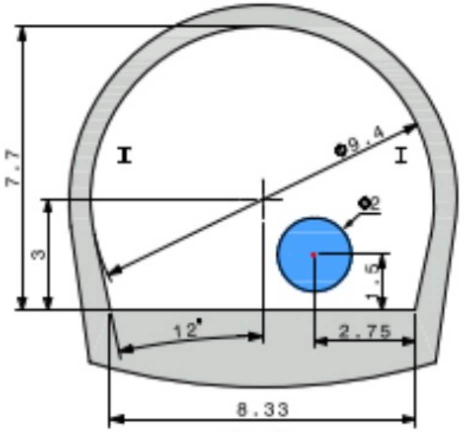
New cavern option:

65m long, 8m wide/high cavern
Connected to surface through
88m high shaft (9.1m diameter):
612m from IP1.

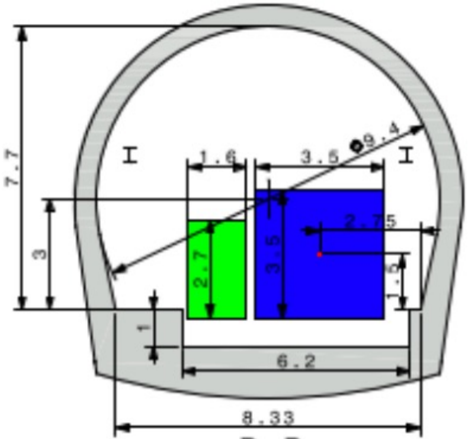




A-A



C-C



D-D

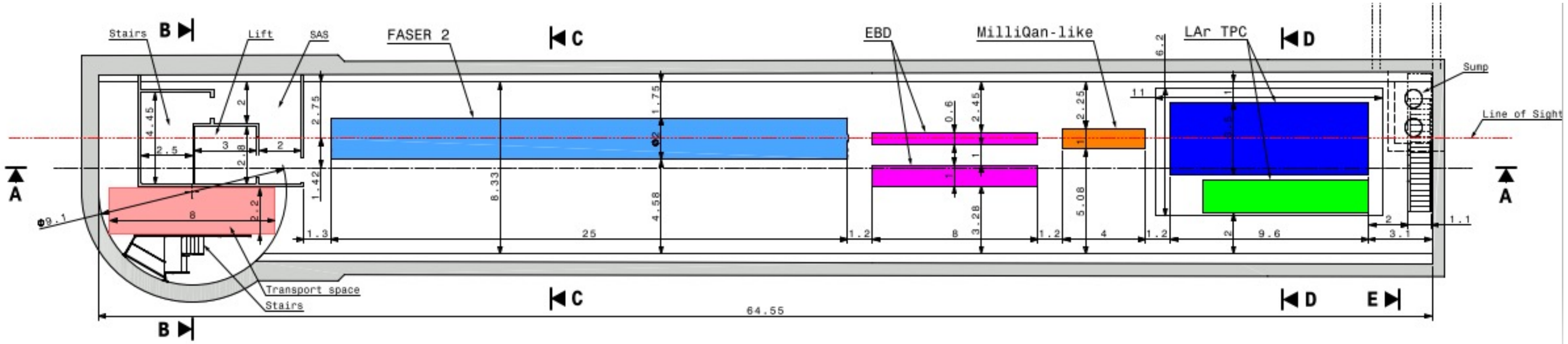
K. Balazs, J. Osborne
CERN SCE

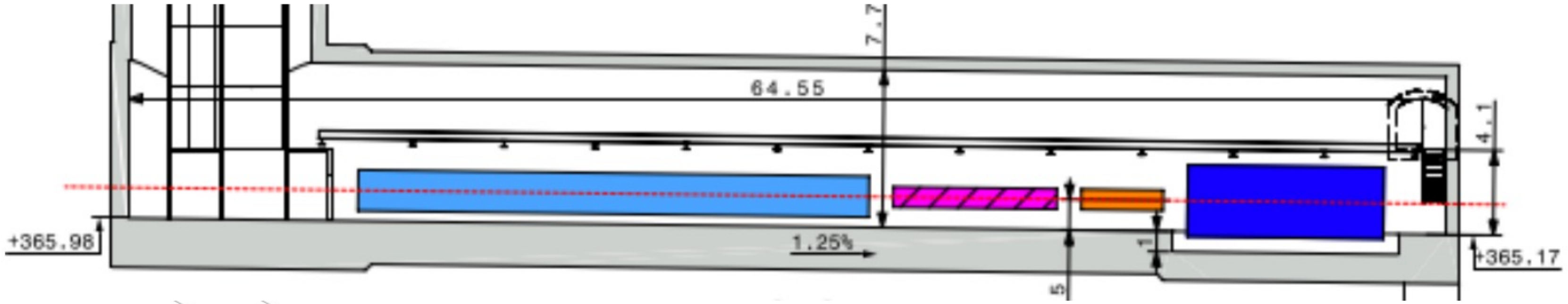
New cavern option:

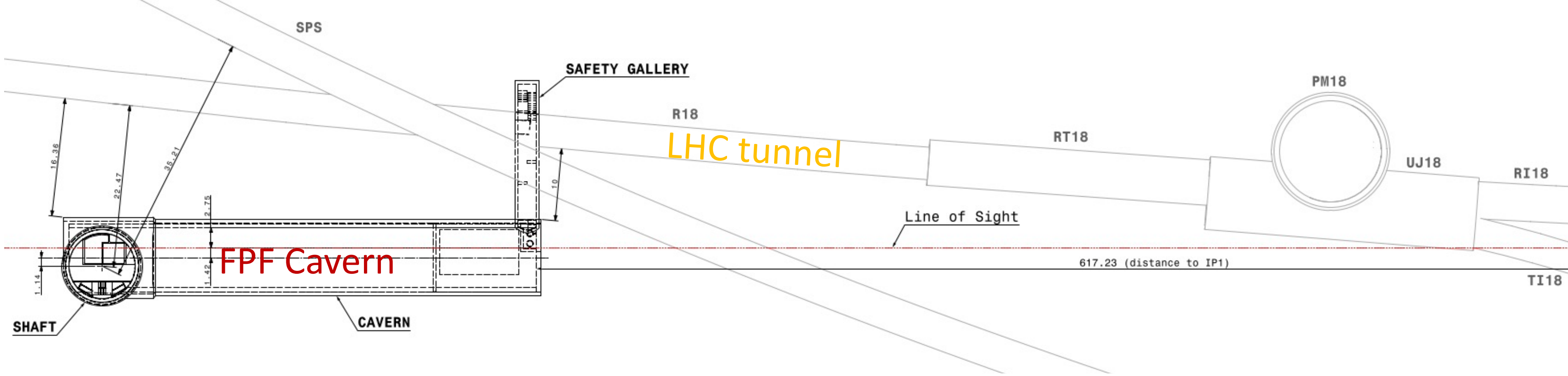
65m long, 8m wide/high cavern
Connected to surface through 88m high shaft (9.1m diameter): 612m from IP1.

New cavern >10m from LHC tunnel. Should mean that can access cavern during LHC operations (from RP point of view) – RP study ongoing.

Connection (safety gallery) from cavern to LHC for emergency evacuation.







First costing of CE works & services

- First costing of civil engineering works for the 2 options
- Based on comparative costing to similar projects:
  - SPS Dump Facility Tunnel eye enlargement as reference point for UJ12 alcoves
  - HL-LHC Point 1 as reference point for new cavern option
- Cost Estimates Class 4
  - Total could be 50% higher and 30% lower than the given estimate
- Pure civil engineering cost estimate 13MCHF for UJ12 alcoves, 23MCHF for new cavern
- Additional cost for services ~15MCHF for new cavern, much less for UJ12 alcoves
- **Total cost: ~40MCHF (new cavern), ~15MCHF (UJ12 alcoves)**

Costing of Services

Item	New Cavern	Comments / Reference
EN-EL	700*	2MVA power (cost does not include include civil engineering for links from SE18 (1.5m under ground)) EDMS 2588617 (M. Lonjon (EN-EL))
Ventillation	7,000	Rough estimate from M. Battistin (EN-CV) based on HL-LHC installation
Access system + ODH + fire-safety + evacuation	2,500	Discussion in dedicated 'safety systems' meeting with EN-AA
Transport infrastructure	1,440	Shaft crane 25tn (570), Cavern crane 25tn(370), Lift (500) (From C. Bertone (EN-HE))
Total	**~12MCHF**	

Based on previous projects these are expected to be the main cost drivers for services.

Contrasting the 2 options

Given the only factor of ~2.5 difference in costs between the 2 options there is a strong preference from the physics side towards the new cavern option:

- No size constraints on the experiments
    - FASER2 physics would be much reduced if restricted to a 6m long alcove
- New cavern would allow a LAr based detector, not allowed in LHC tunnel due to safety constraints
- Access to the experimental area much easier for new cavern option
    - Requirements on size/weight of apparatus for installation
    - Access for maintenance during beam operation (RP study ongoing)
- Radiation for detector electronics/components would be significantly less in new cavern
- Beam background maybe problematic for some experiments (neutrino/DM) in alcoves, will not be the case for the new cavern
    - During LHC pilot beam in 2021, FASER saw background events in time with beam-1 passing UJ12. The normalized losses were significantly higher than in physics running, but this still could present a relevant background for FPF experiments in UJ12 alcoves
- Much of the excavation work and the installation of services/experiments could be done during LHC operations for the new cavern – reducing possible schedule pressure during LSs

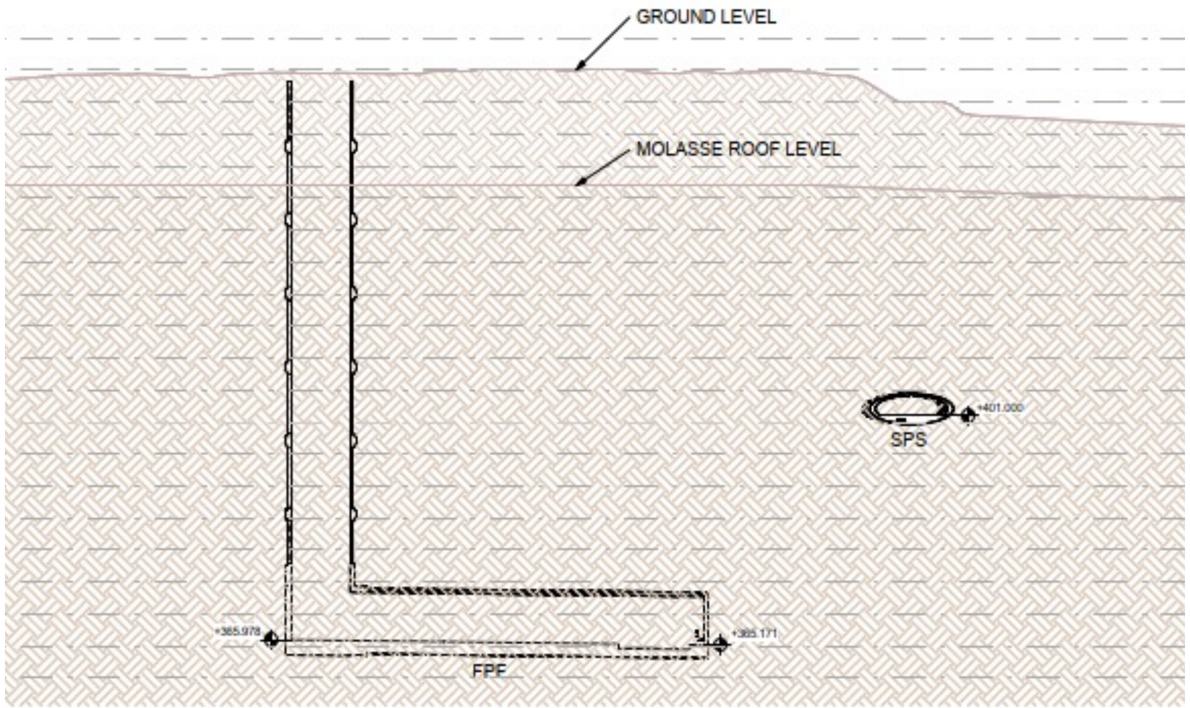
Strong preference from commnity to push for the New Cavern option!

K. Balazs, J. Osborne
CERN SCE

Ongoing work: Surface building Study

- Ongoing study regarding the arrangement of surface buildings, space and landscape within the site

PLAN VIEW - SITE
Sc. 1 : 1000

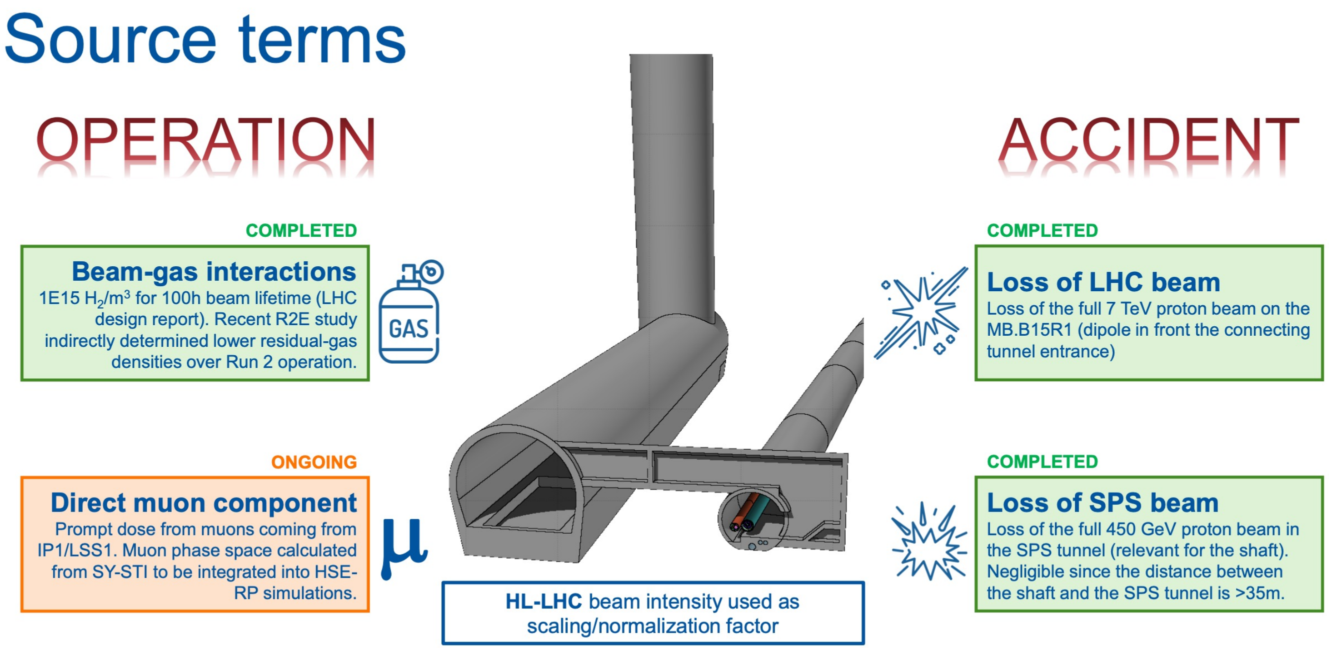


SECTION 1
Sc. 1 : 500

L. Elie, A. Infantino, M. Maietta, H. Vincke (HSE-RP)

RP Study

- An RP study has been carried out to assess if people can access the FPF cavern during HL-LHC operations which would be a significant benefit



Source terms

OPERATION

COMPLETED

Beam-gas interactions
1E15 H_2/m^3 for 100h beam lifetime (LHC design report). Recent R2E study indirectly determined lower residual-gas densities over Run 2 operation.

ONGOING

Direct muon component
Prompt dose from muons coming from IP1/LSS1. Muon phase space calculated from SY-STI to be integrated into HSE-RP simulations.

HL-LHC beam intensity used as scaling/normalization factor

ACCIDENT

COMPLETED

Loss of LHC beam
Loss of the full 7 TeV proton beam on the MB.B15R1 (dipole in front the connecting tunnel entrance)

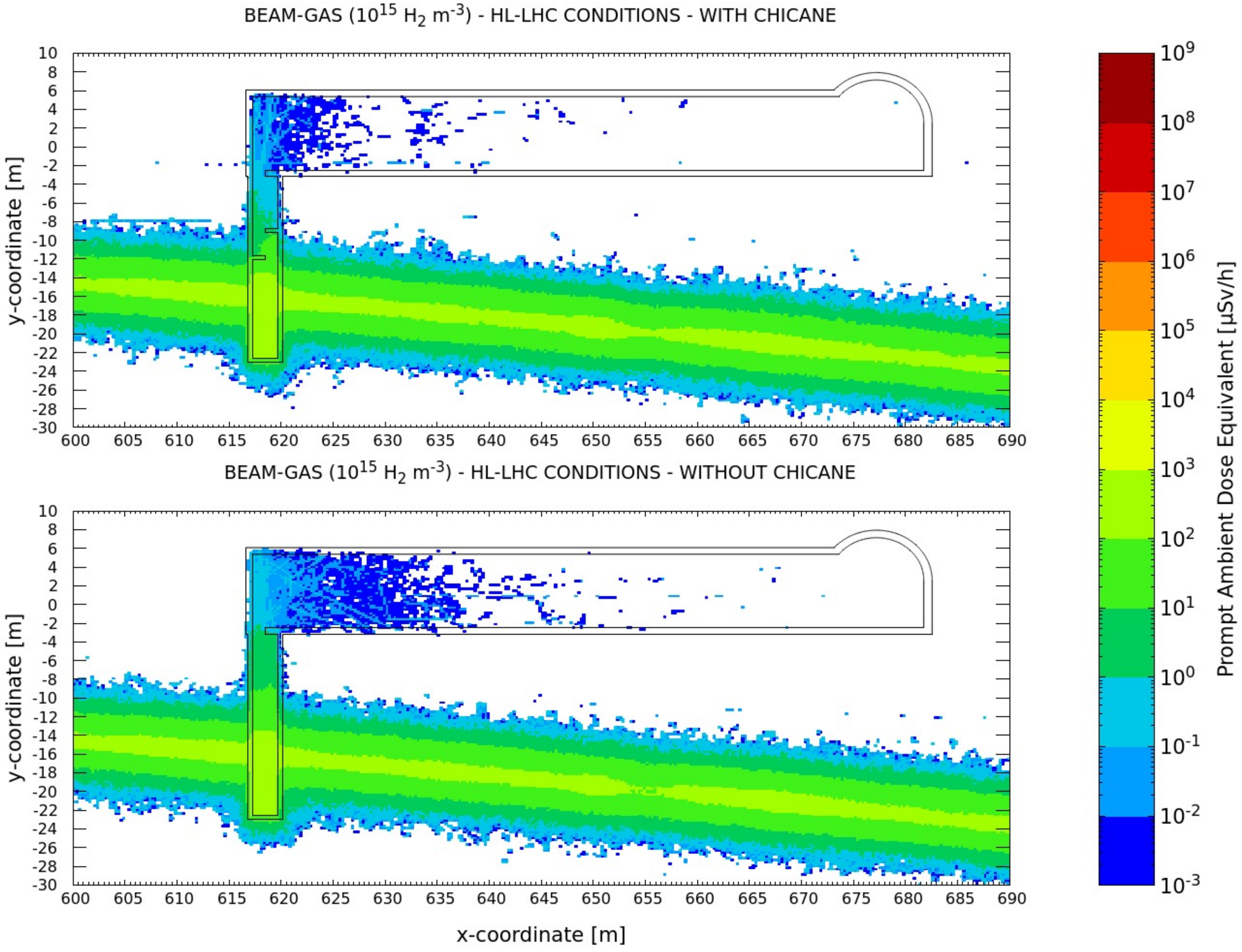
COMPLETED

Loss of SPS beam
Loss of the full 450 GeV proton beam in the SPS tunnel (relevant for the shaft). Negligible since the distance between the shaft and the SPS tunnel is >35m.

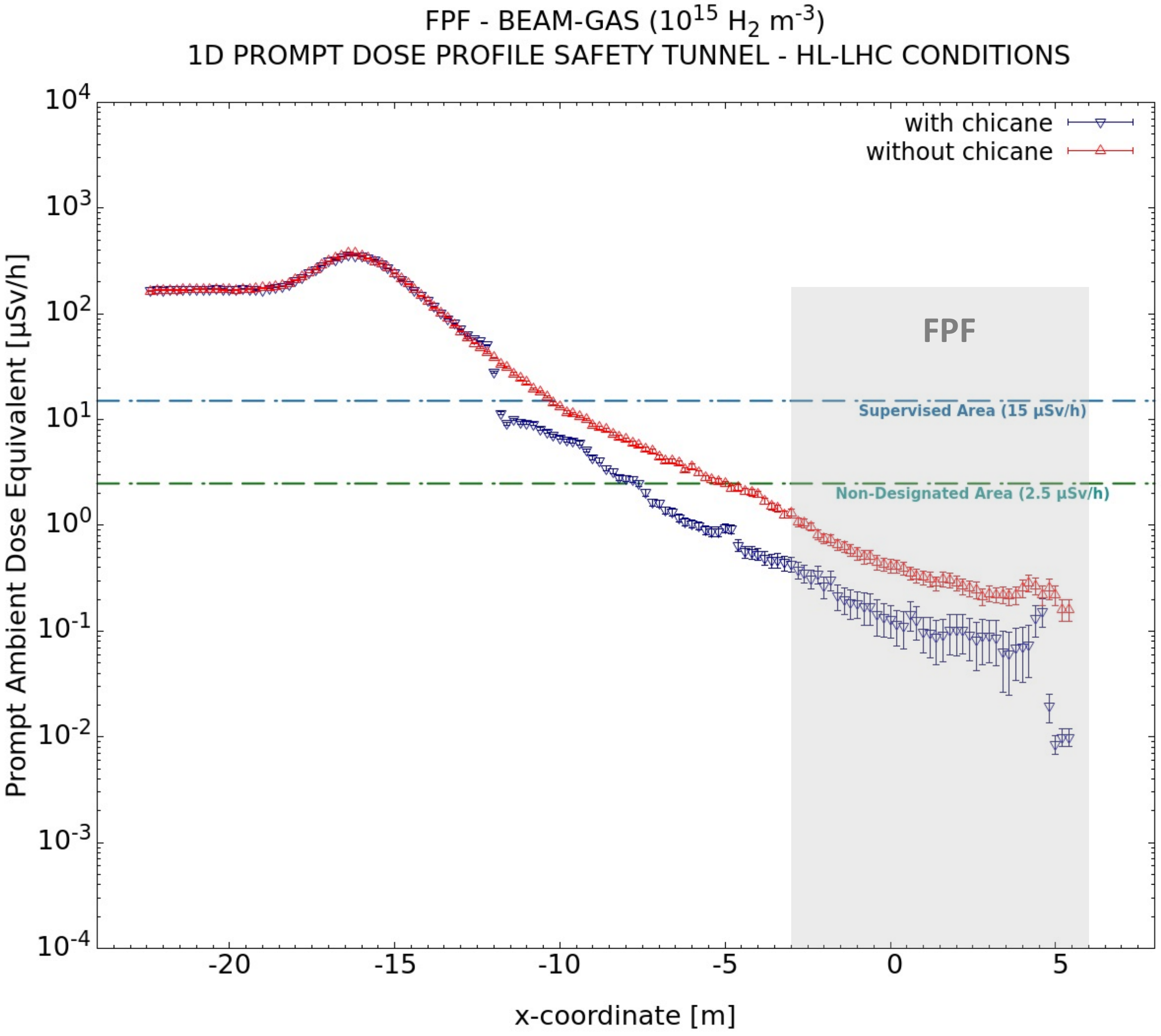
- Detailed FLUKA simulations run to assess the different components
  - SPS losses not a problem
  - Beam-gas not a problem
  - Accidental loss of full LHC beam in worst place – radaiation level too high, updates to chicane in safety gallery being studies
  - Prompt muon dose – under study

L. Elie, A. Infantino, M. Maietta, H. Vincke (HSE-RP)

RP Study – beam gas

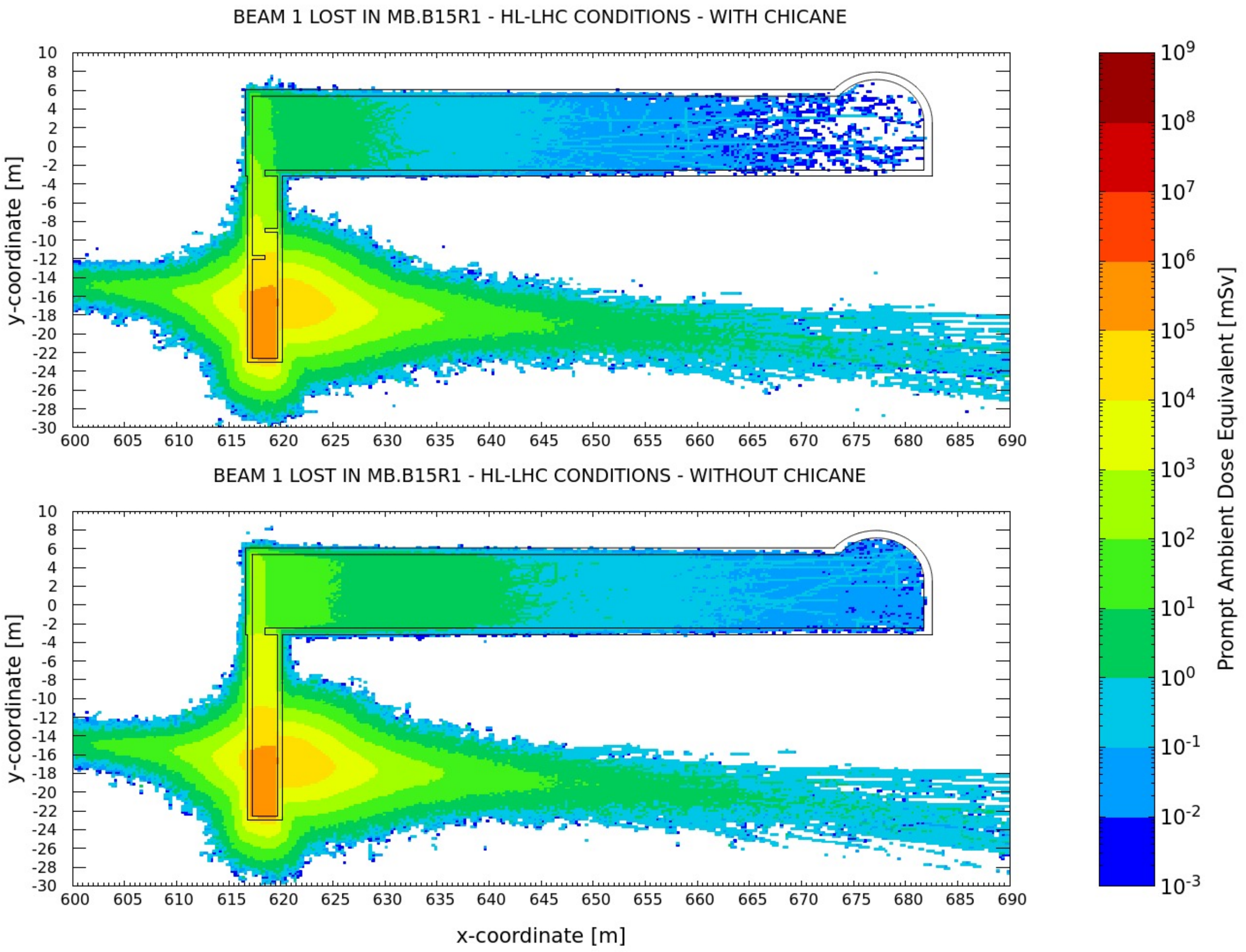

BEAM-GAS (10^{15} H_2 m^{-3}) - HL-LHC CONDITIONS - WITH CHICANE

BEAM-GAS (10^{15} H_2 m^{-3}) - HL-LHC CONDITIONS - WITHOUT CHICANE

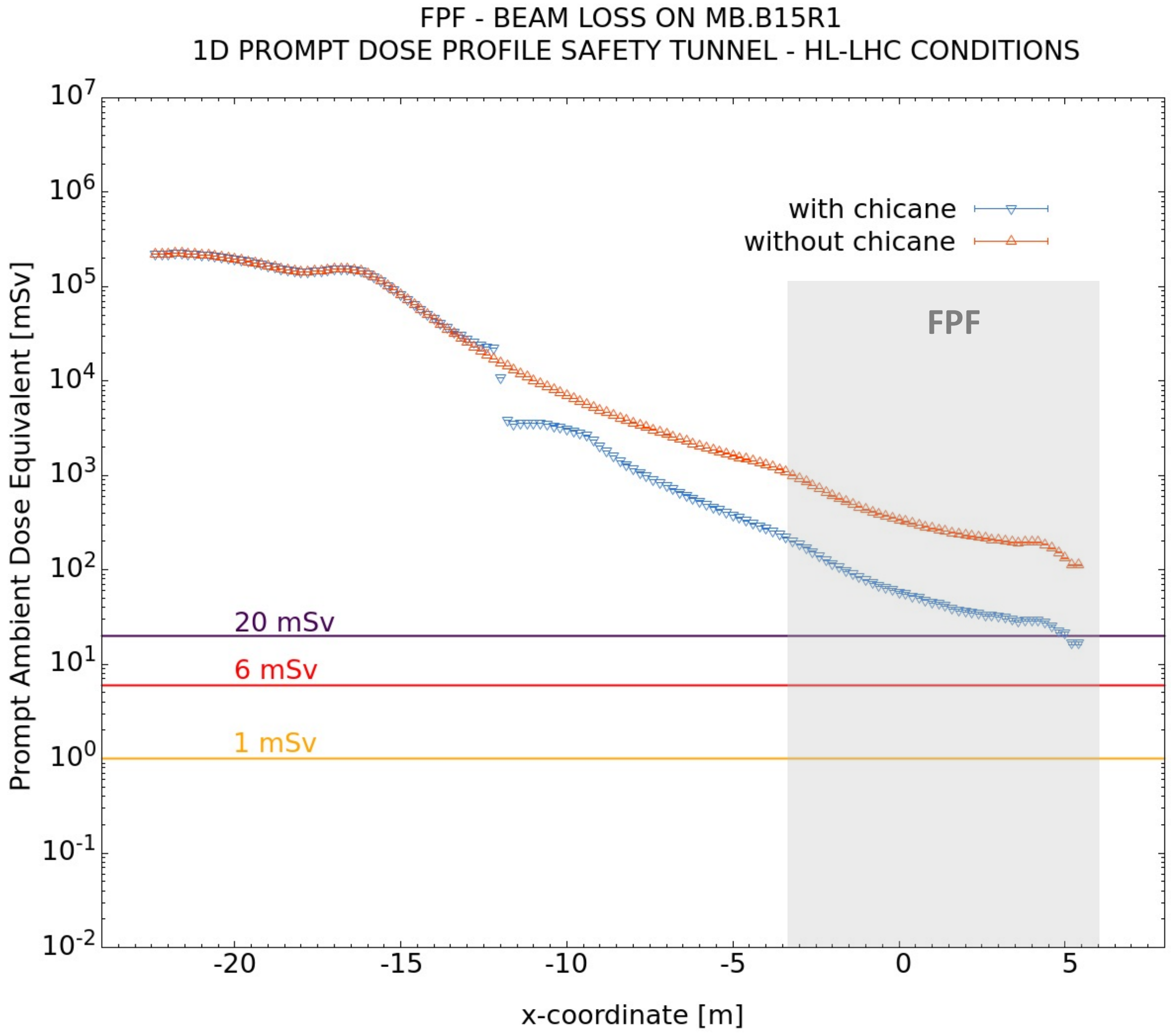

FPF - BEAM-GAS (10^{15} H_2 m^{-3})
1D PROMPT DOSE PROFILE SAFETY TUNNEL - HL-LHC CONDITIONS

L. Elie, A. Infantino, M. Maietta, H. Vincke (HSE-RP)

RP Study – Accidental LHC beam loss


BEAM 1 LOST IN MB.B15R1 - HL-LHC CONDITIONS - WITH CHICANE

BEAM 1 LOST IN MB.B15R1 - HL-LHC CONDITIONS - WITHOUT CHICANE

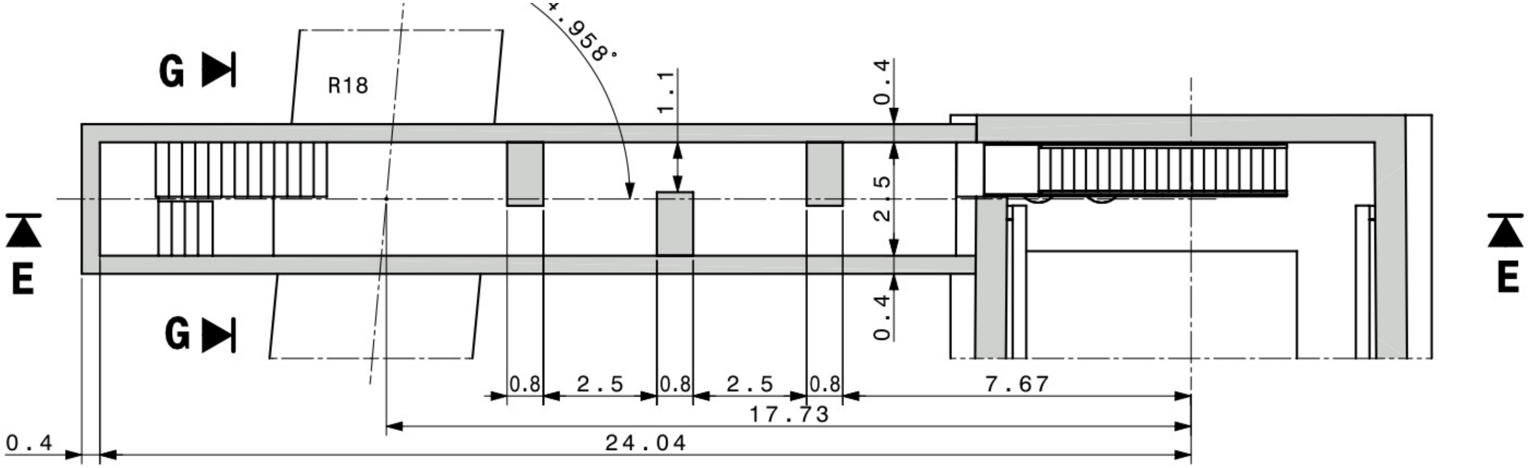

FPF - BEAM LOSS ON MB.B15R1

1D PROMPT DOSE PROFILE SAFETY TUNNEL - HL-LHC CONDITIONS

Chicane in safety gallery reduces the dose but not enough

RP Study – Accidental LHC beam loss

- After a discussion with safety, CE and RP - Propose to:
  - Double thickness of walls in chicane (40cm -> 80cm)
  - Add additional wall
  - Reorder walls and increase their lengths
- RP Study to be redone with update chicane geometry to see if this will sufficiently reduce the dose in the cavern



Plan view - Safety gallery

RP Study – Accidental LHC beam loss

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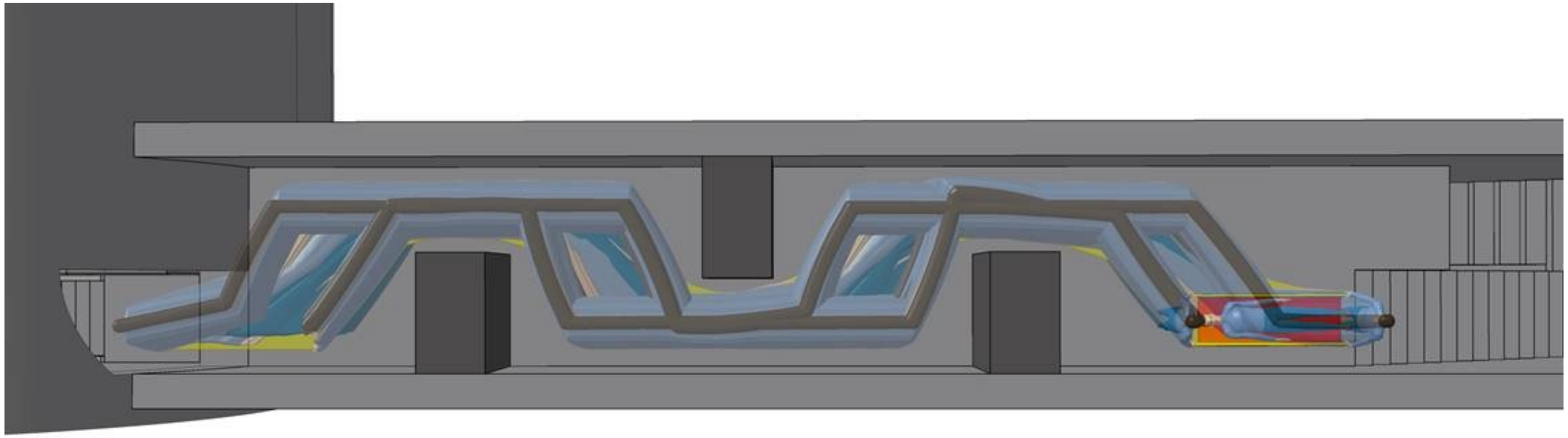
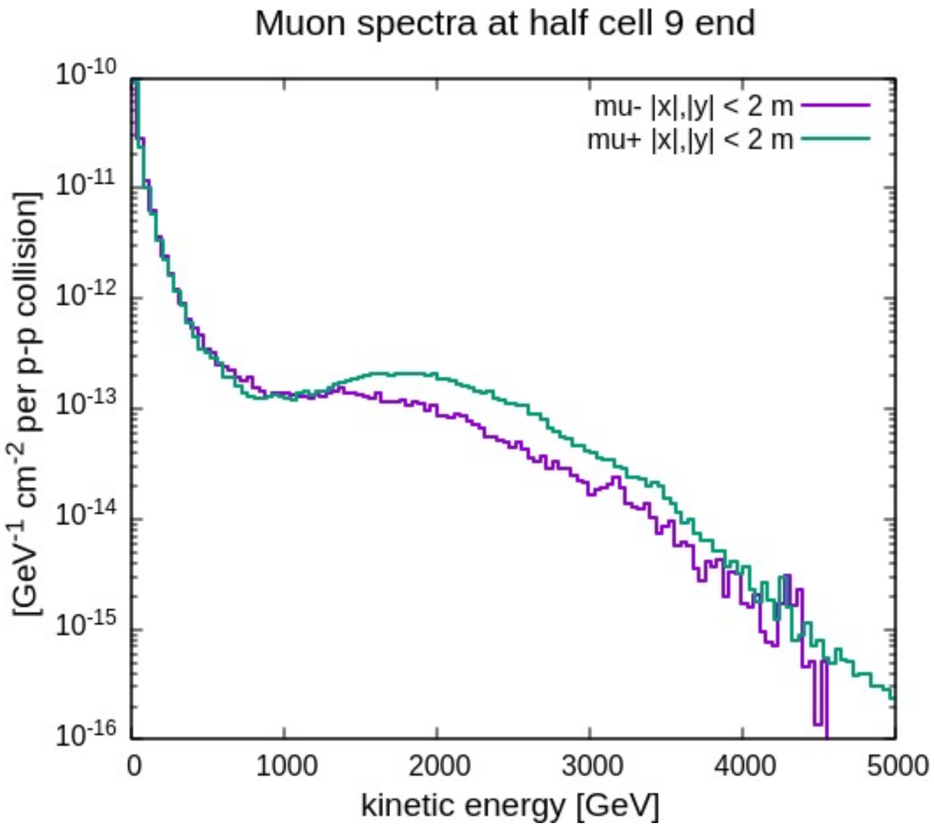


FLUKA study of FPF background

- FLUKA team running simulations to estimate the expected (muon) background in the FPF
- Background rate important for:
    - Experiment design
    - RP study (dose from muons)
    - Study of sweeper magnet (see next slides)
- In order to study sweeper magnet ~400m from IP1, muon flux estimated in $4x4m^2$ square around LOS at ~350m from IP1
- As a second step these muons will be propagated to the FPF (through ~250m of rock)
    - In progress…
- Spectra is quantitavely different from LHC setup – traced to change in crossing plane in IP1 for HL-LHC
    - Detailed understanding of this still to be understood



F. Cerutti, M. S. Gilarte (SY-STI)

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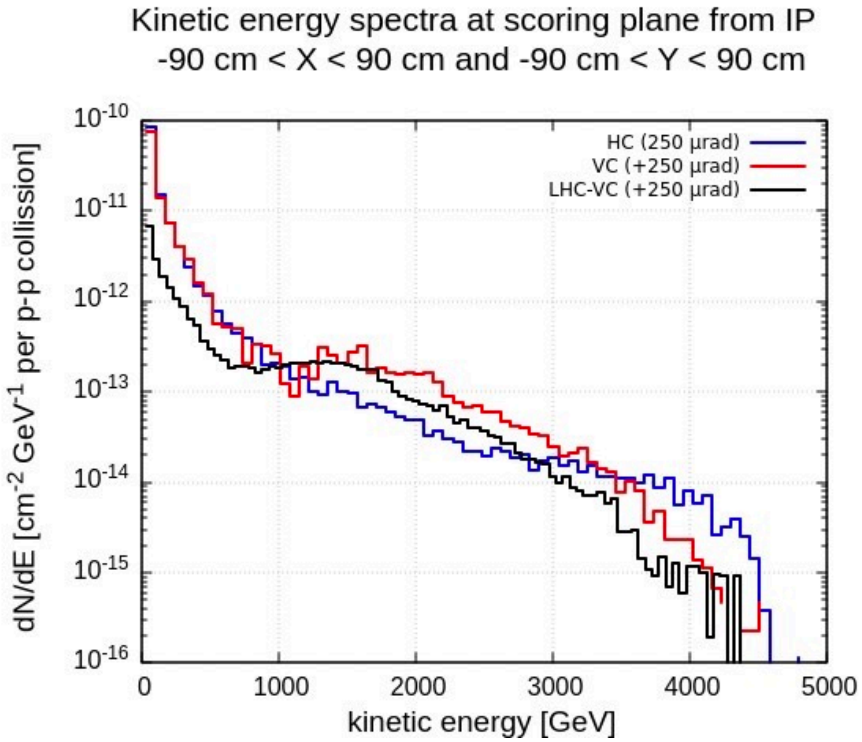
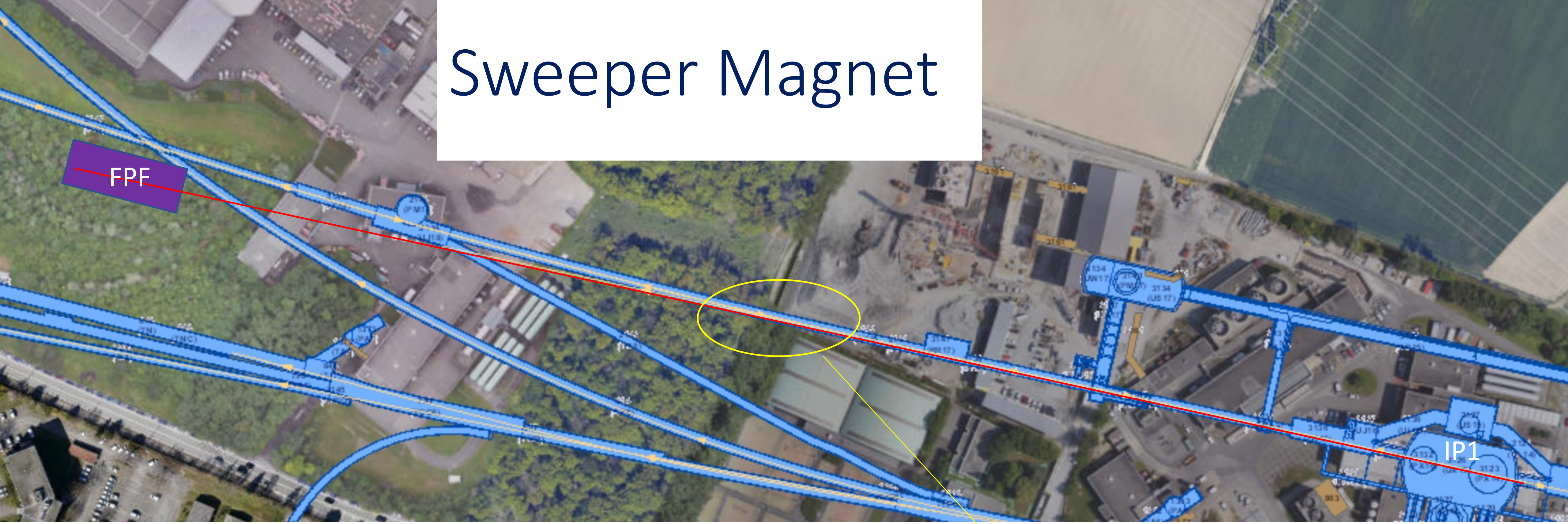
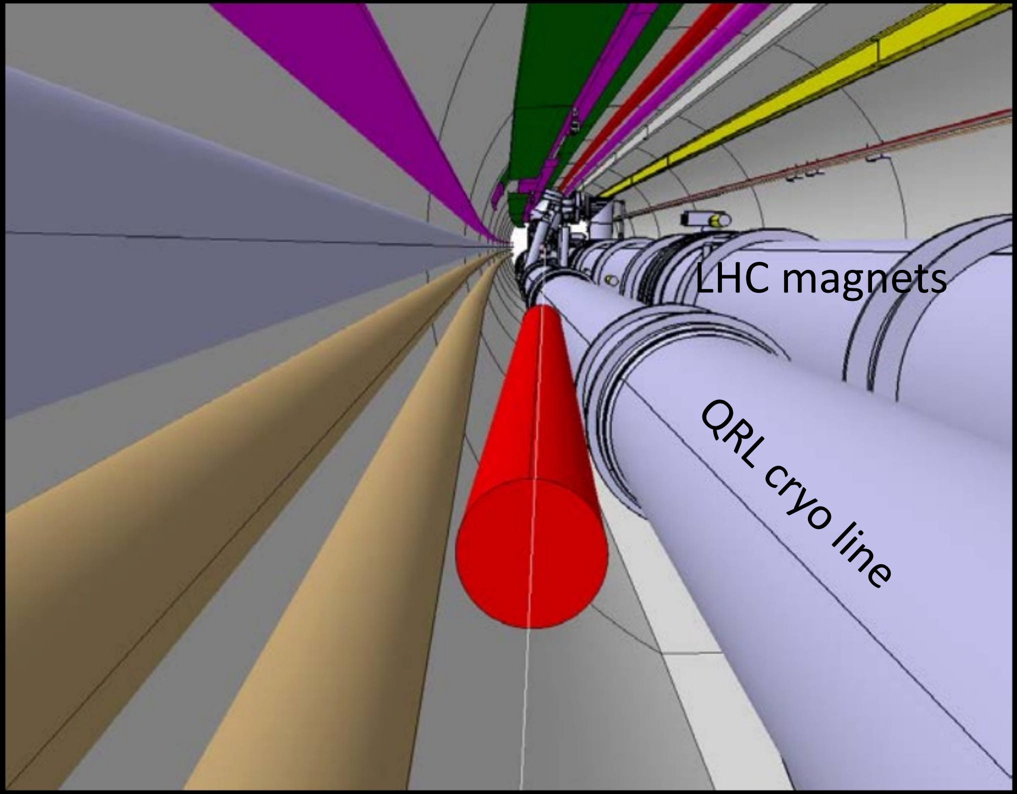


Sweeper Magnet

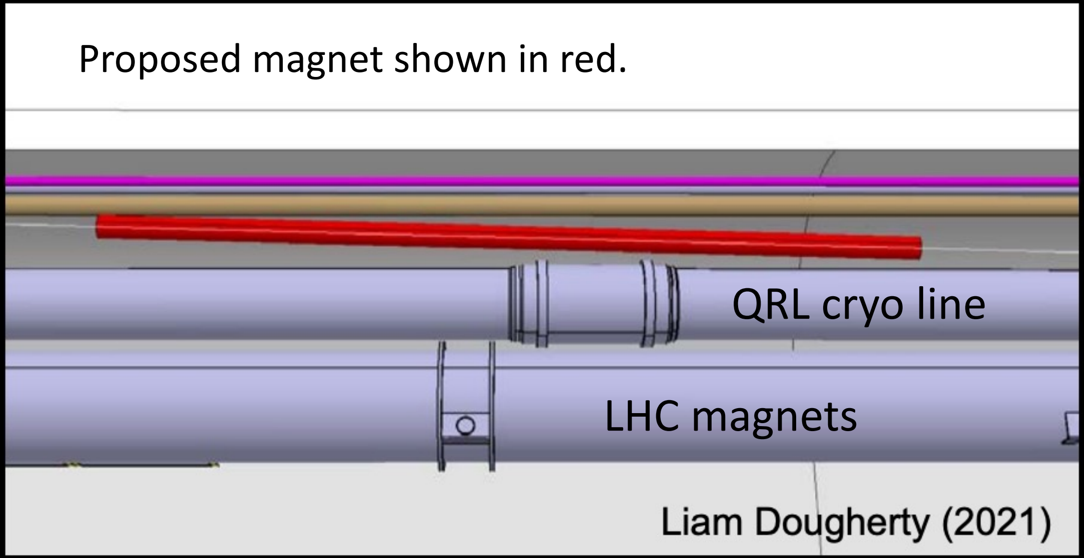


Background muons coming from IP1 collisions go through FPF (~1.5Hz/cm^2) on LOS, higher away from LOS.
Placing a sweeper magnet on the LOS can deflect these muons and reduce the background – which could be very important/essential for physics - e.g. reducing the number of times emulsion would need to be replaced.
Best place for such a magnet would be between where LOS leaves LHC magnets and where it leaves the LHC tunnel (200m lever-arm for deflected muons).
Studies related to such a magnet ongoing

Sweeper Magnet: Initial Studies



$$h_B \approx \frac{ecd}{E_\mu} B\ell = 60\ \mathrm{cm} \left[\frac{100\ \mathrm{GeV}}{E_\mu}\right] \left[\frac{d}{200\ \mathrm{m}}\right] \left[\frac{B \cdot \ell}{\mathrm{T} \cdot \mathrm{m}}\right]$$


Proposed magnet shown in red.

Liam Dougherty (2021)

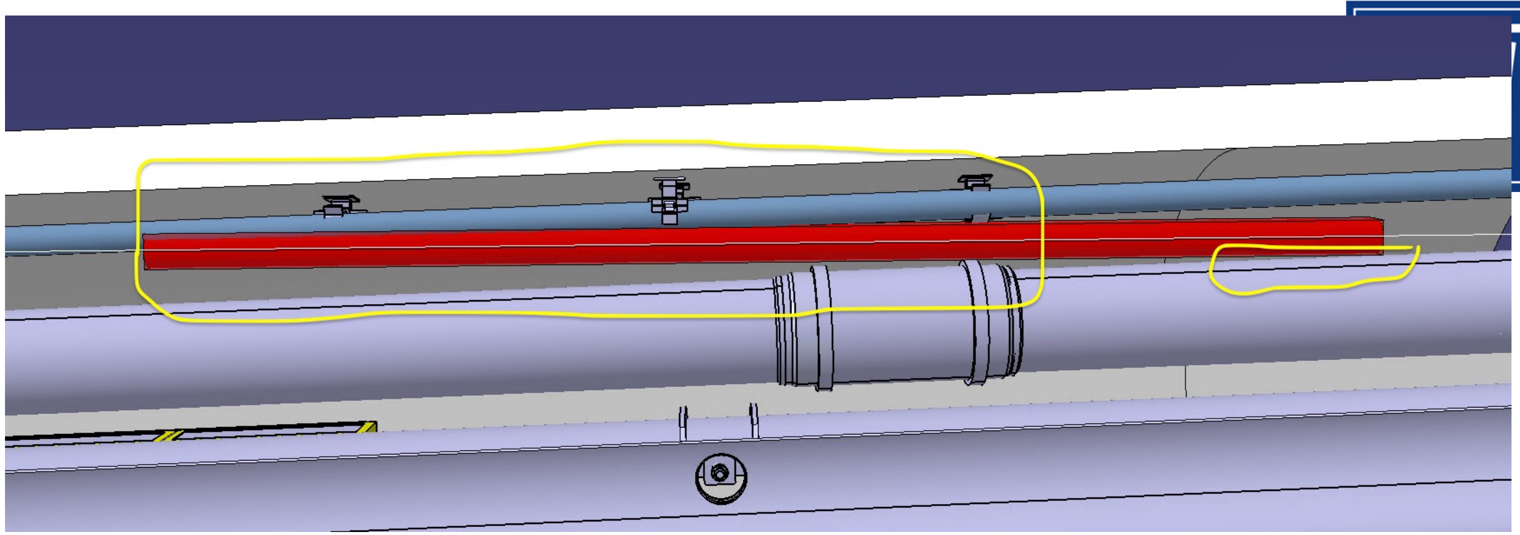
Initial studies using the integration model of the LHC, suggested that a 7m-long / 20cm-diamater magnet could be placed on the LOS in the LHC tunnel. Assuming a 1T/m this would give 7Tm of bending power with a lever-arm of 200m. Looked quite promising!

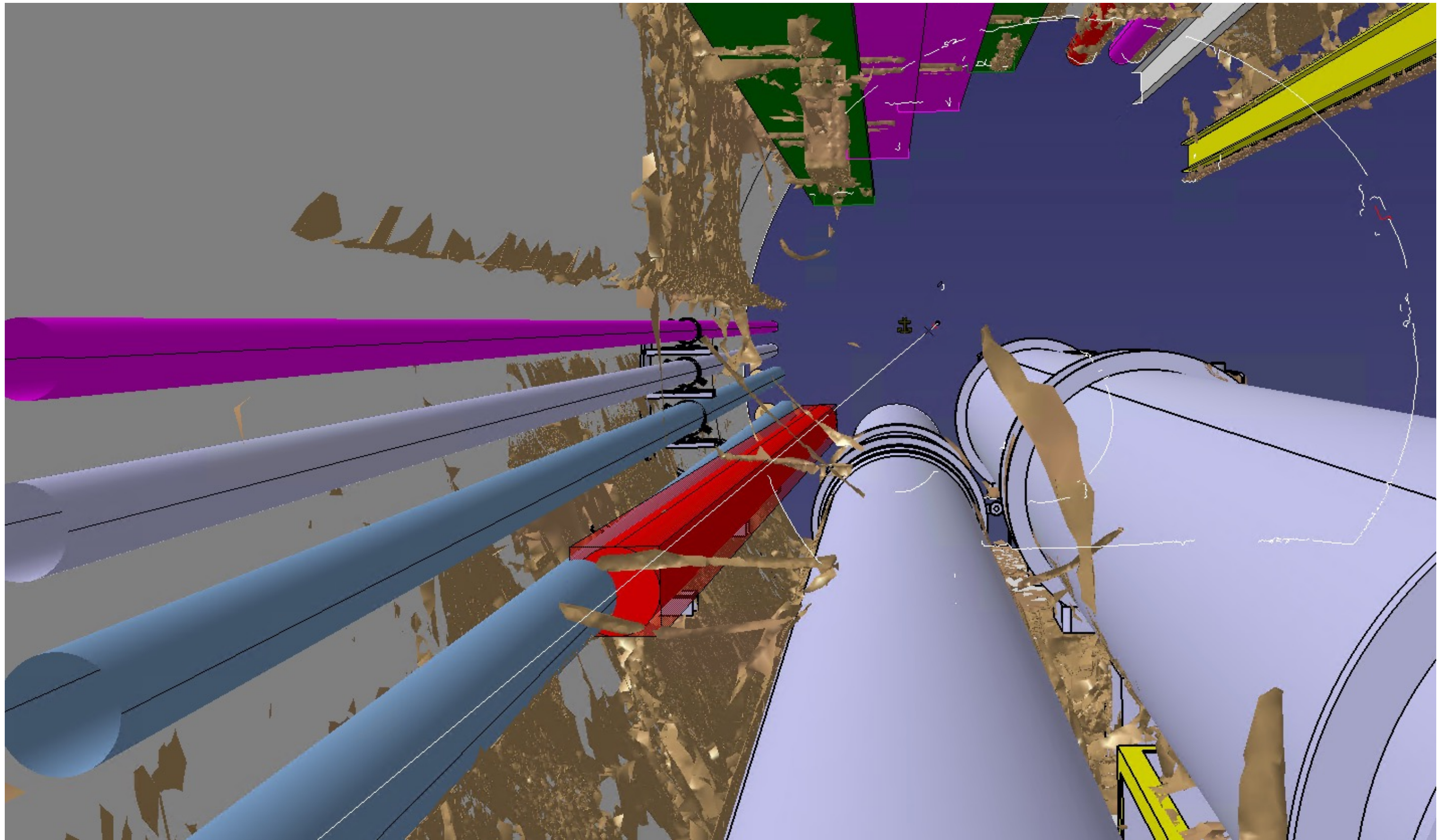
For FPF d ~ 200m
100 GeV muons would be bent ~4.2m from LOS for 7Tm field

L. Dougherty (CERN EN-ACE)

Further Studies

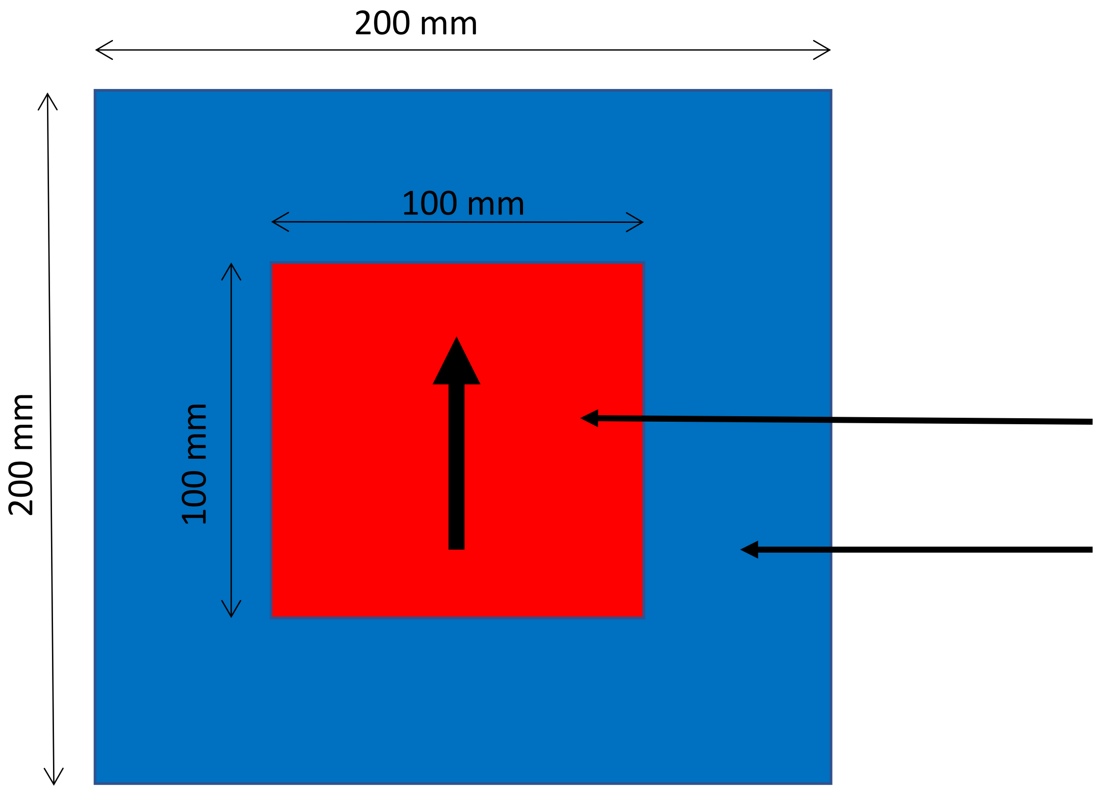
- To investigate further a laser scan was taken in the relevant region of the LHC tunnel.
- Unfortunately this revealed a number of items (pipes, infrastructure) not included in the original integration model.
- This means in the current situation 70% of the proposed magnet is clashing with installed cryogenic infrastructure (mostly the Warm Return Line (WRL)).
- We need to see with the LHC cryo team if we could modify the WRL in this area to free up space to be able to install a longer magnet.
- We also need to investigate the magnet support and handling equipment for the installation/removal.
- A further complication is the beam crossing angle which will move the LoS ~10cm towards the tunnel wall at this location.





Sweeper Magnet: Possible Magnet Design

- Simple design with the permanent magnetic blocks placed at the center of the assembly (no open aperture needed).
- The efficiency of the magnet is very good.
- The field homogeneity inside the window of 100 x 100 mm is very good (≈ +/- 1%).
- We could imagine to use NdFeb magnets if the radiation / energy deposit stay low at the magnet location (to be studied)



Permanent magnet (SmCo or NdFeb)

External ring (construction steel)

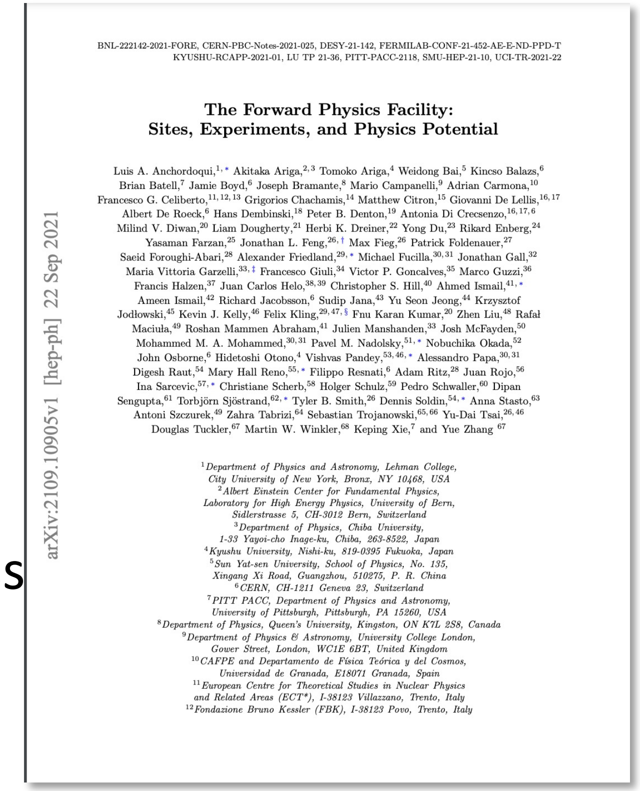
Pictured: FASER sweeping magnet

- Possible construction in 7 x 1m long sections
- Total weight 2.3tonnes => 330kg/section
- Expected cost ~150kCHF (cheap!)
  - Not including cryo changes, supports etc..
- Need to consider integration aspects (support / handling etc..)

P. Thonet (CERN, TE-MSC)

FPF workshops & paper

- There have been 3 FPF workshopover the last year, the latest 2 weeks ago:
  - https://indico.cern.ch/category/14436/
  - Mostly reporting progress on theory level physics studies for FPF
  - Clear there is a strong physics motivation and community support
- A short (74page) paper summarizing the FPF studies was released in Sept.
  - https://arxiv.org/pdf/2109.10905.pdf
- A second longer paper is planned to be finalized in Feb 2022
- The FPF is being actively discussed in many of the tracks of the US Snowmass process, with significant interest expressed
- The project needs to transition towards more detailed designs of the experiments and how these effect the facility design and required infratsructure and services



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KYUSHU-RCAPP-2021-01, LU TP 21-36, PITT-PACC-2118, SMU-HEP-21-10, UCI-TR-2021-22

arXiv:2109.10905v1 [hep-ph] 22 Sep 2021

The Forward Physics Facility:
Sites, Experiments, and Physics Potential

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Snowmass 2021

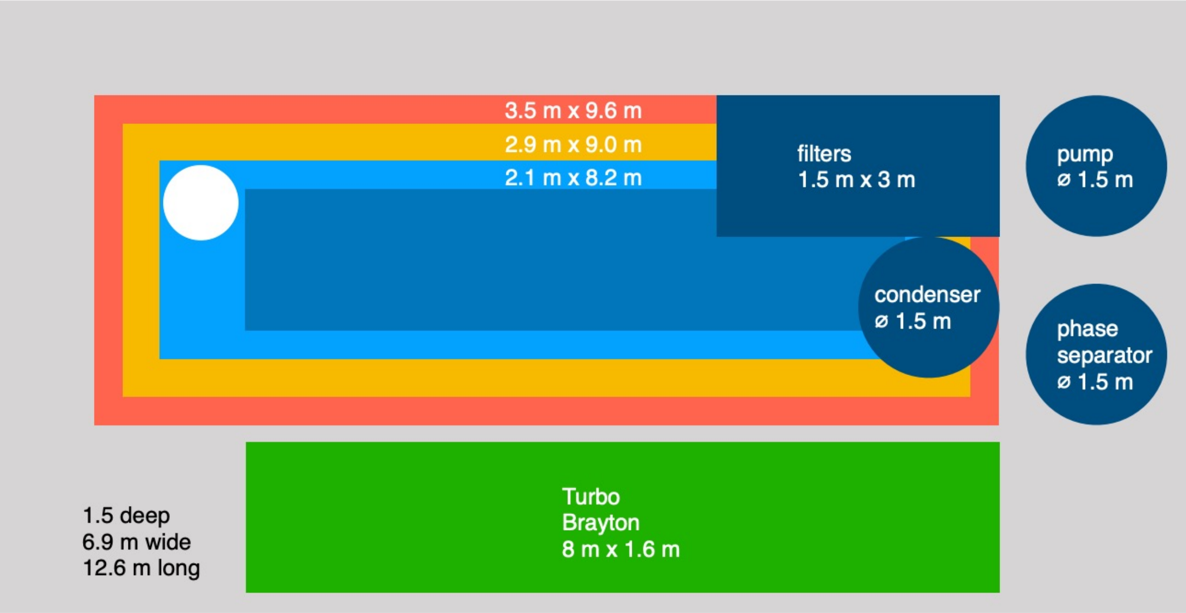
Summary

- FPF is a proposed facility to house several BSM and neutrino experiments on the IP1 collision axis line of sight
- Strong physics motivation:
  - BSM, neutrino physics, QCD and input for astroparticle experiments
  - Maximizing the physics potential of the LHC in the high-luminosity era:
    - **Opening new areas of physics**: Precision tau neutrino studies, collider produced dark matter scattering
- Two options looked at
  - Preliminary costings suggesting the new cavern would be the best value for physics return
- Proposed next steps:
  - More detailed physics studies (with realistic experimental effects included) to bolster physics case
  - More detailed experiment design, and service/infrastructure requirements to be fed into next itteration of facility design
  - More detailed studies on background / radiation and sweeper magnet design
    - RP study and muon flux simulations ongoing: see talks at last FPF workshop for more details
- Many thanks to the strong support of the PBC

Backup…

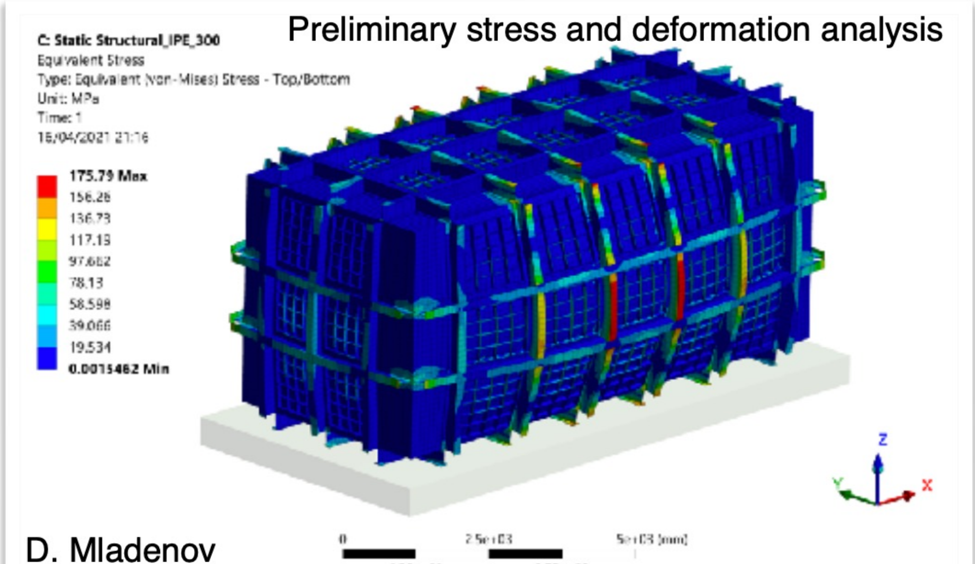
LAr TPC cryogenics and cryostat

LAr TPC detector drives many aspects of services/infrastructure and safety systems.
Rough design of cryostat and cryogenics by F. Resnati based on proto-Dune experience in the neutrino platform.



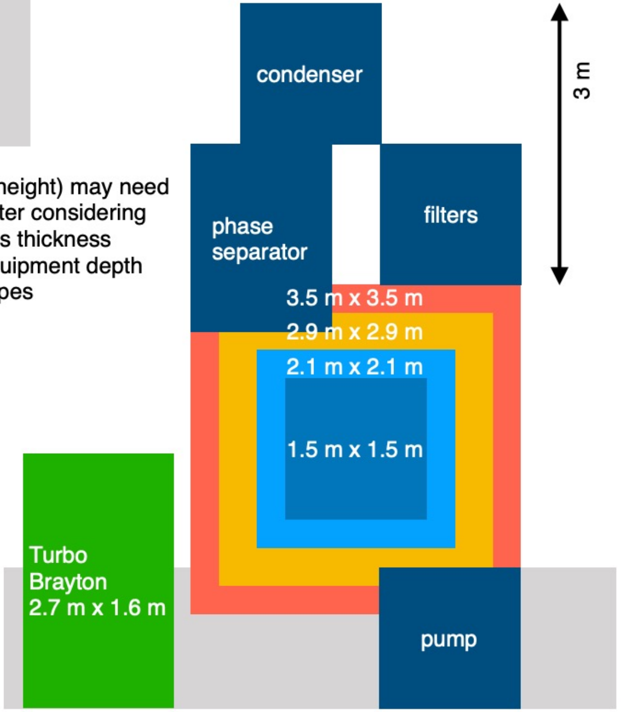
- Reduced to 30 cm the non-instrumented LAr layer.
- Insulation thickness reduced to 40 cm (~increase the heat input (*O*(4 kW)).
- Reduce structural thickness.
- Manhole for egress added.

Preliminary stress and deformation analysis



D. Mladenov

Dimensions (height) may need to increase after considering
- minimum gas thickness
- minimum equipment depth
- cryogenic pipes



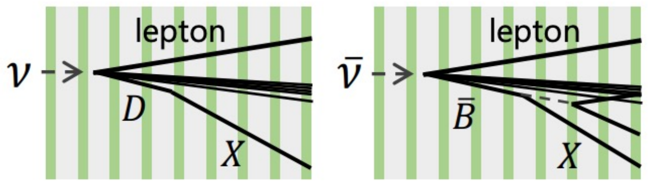
Physics potential:
high-energy neutrino interactions

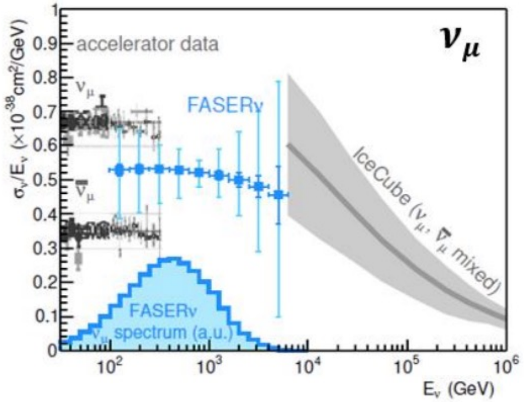
- Primary goal: cross section measurements of different flavors at TeV energies
  - where no such measurements currently exist.

- NC measurements
  - Could constrain neutrino non-standard interactions (NSI).

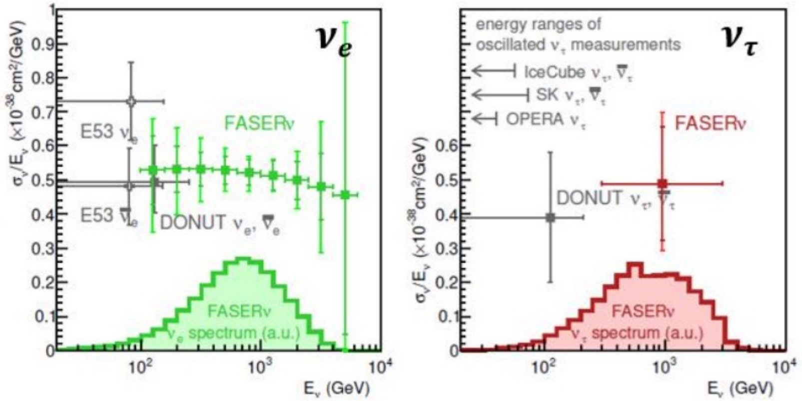
- Neutrino CC interaction with charm production ($\nu s \rightarrow lc$)
  - Study the strange quark content.
  - Probe inconsistency between the predictions and the LHC data [Eur. Phys. J. C77 (2017) 367].
- Neutrino CC interaction with beauty production
  - Has never been detected.

CC heavy quark production





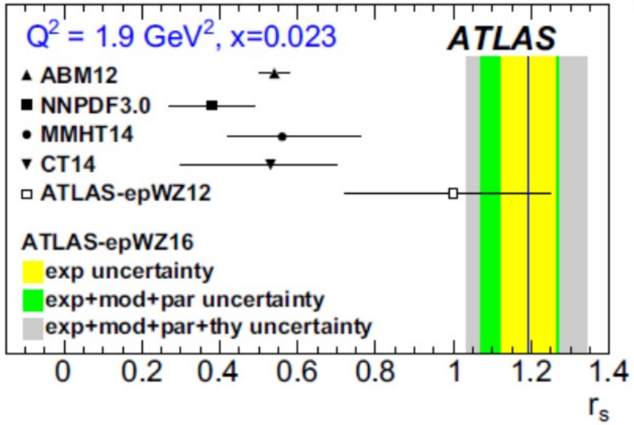
FASER Collaboration,
Eur. Phys. J. C 80 (2020) 61,
arXiv:1908.02310

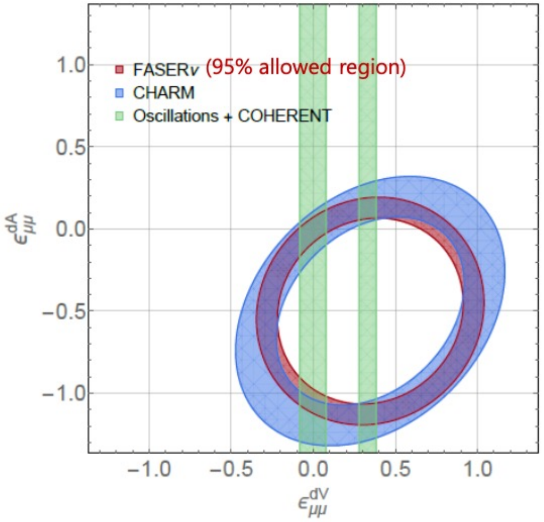


A. Ismail, R.M. Abraham, F. Kling,
Phys. Rev. D 103, 056014 (2021),
arXiv:2012.10500

Eur. Phys. J. C77 (2017) 367

$$r_s = \frac{s + \bar{s}}{2\bar{d}}$$



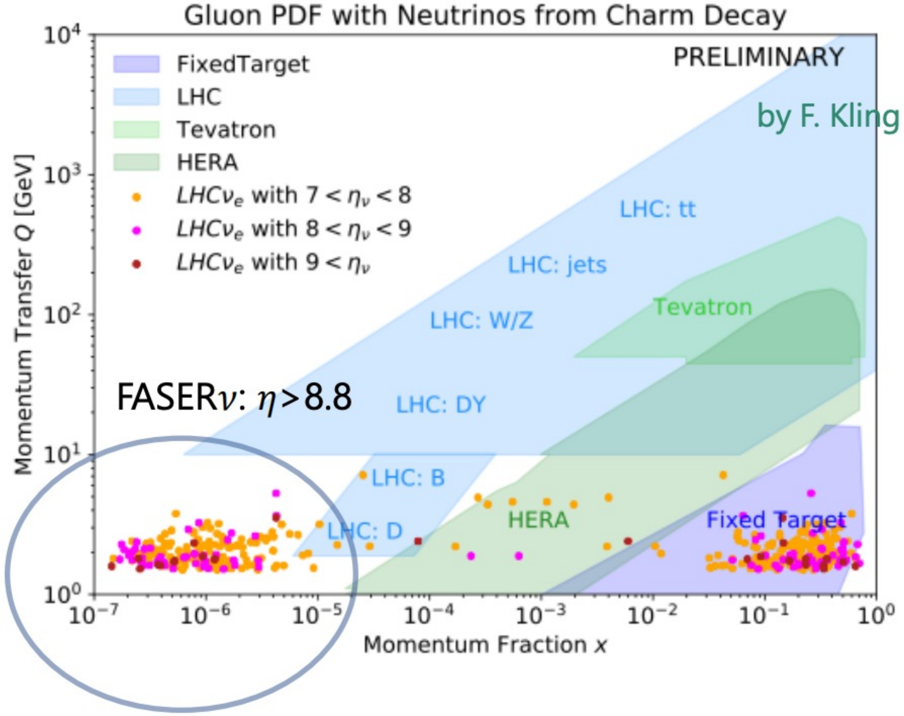


Physics potential:
forward particle production

- Neutrinos produced in the forward direction at the LHC originate from the decay of hadrons, mainly pions, kaons, and charm particles.

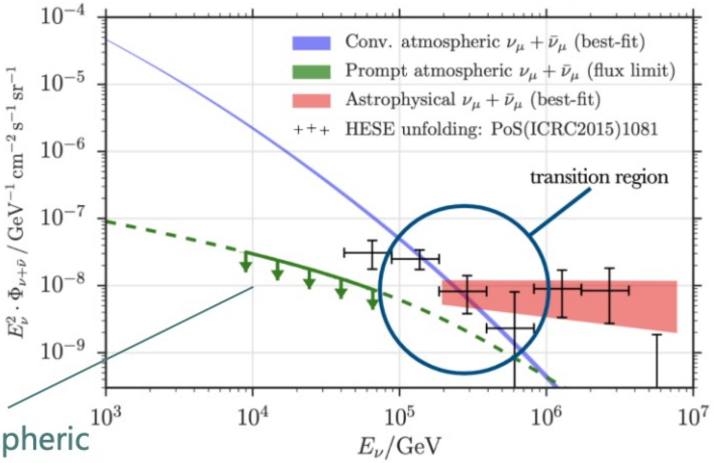
- Forward particle production is poorly constrained by other LHC experiments.
- FASERν's measurements provide novel input to validate/improve generators.
  - First data on forward kaon, hyperon, charm

- Neutrinos from charm decay could allow to
  - test transition to small-x factorization, see effects of gluon saturation, constrain low-x gluon PDF, probe intrinsic charm.
- Relevant for neutrino telescopes (such as IceCube).
  - In order for IceCube to make precise measurements of the cosmic neutrino flux, accelerator measurements of high energy and large rapidity charm production are needed.
  - As 7+7 TeV p-p collision corresponds to 100 PeV proton interaction in fixed target mode, a direct measurement of the prompt neutrino production would provide important basic data for current and future high-energy neutrino telescopes.



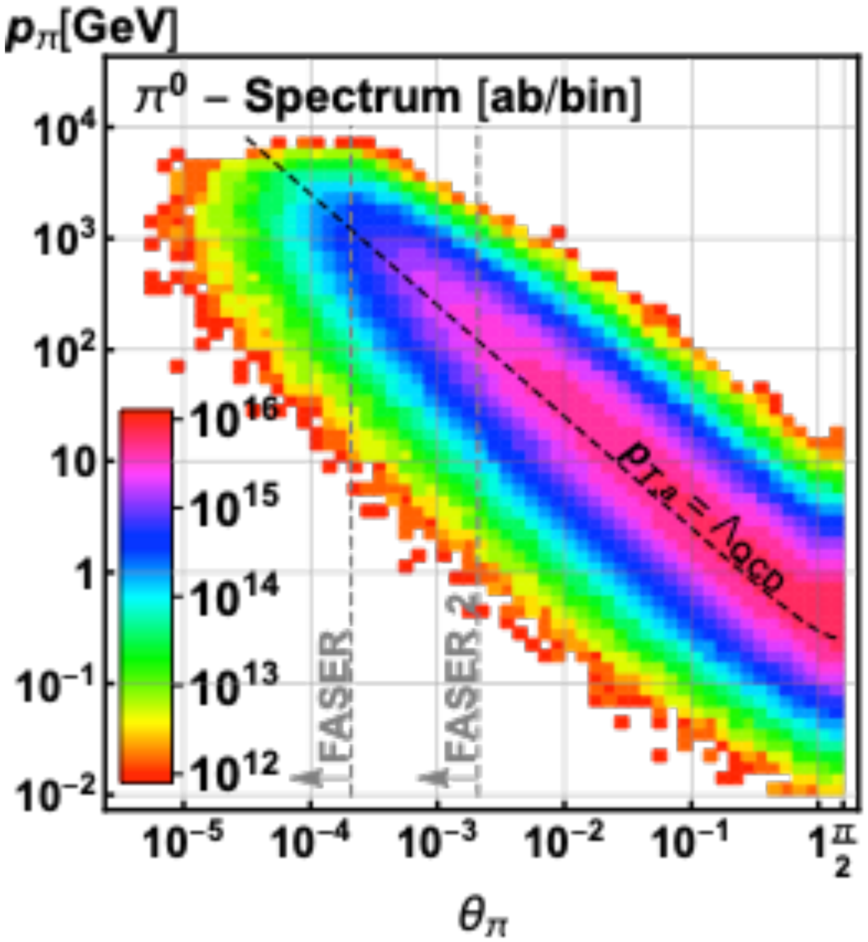
by F. Kling

IceCube Collaboration,
Astrophys. J. 833 (2016)



prompt atmospheric
neutrinos

PION 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,

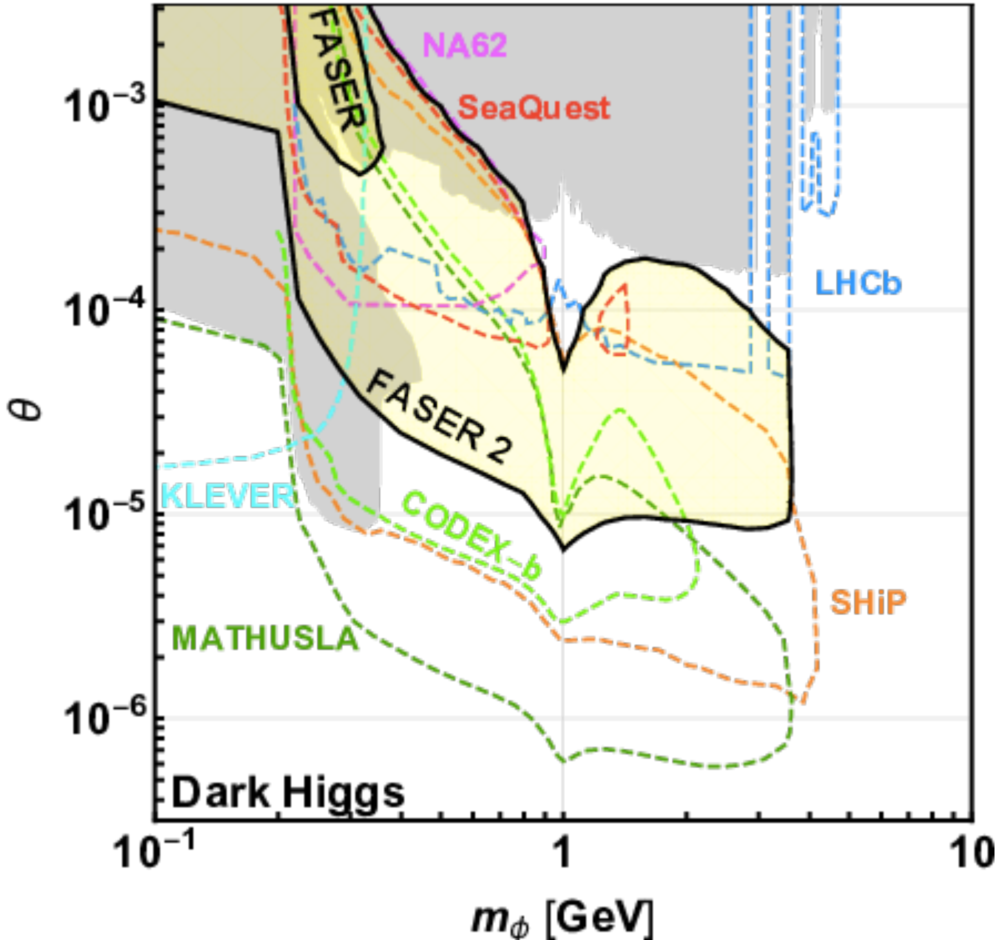
- 2% of π^0s fall in FASER acceptance;
- whereas the FASER acceptance covers just (2×10^{-6})% of the solid angle.

Run-3 (0.15/ab) will produce a huge number of π^0s in FASER angular acceptance. Even with large suppression ($\varepsilon^2 \sim 10^{-8} – 10^{-10}$ for relevant region of parameter space) can still have very large number of dark photons produced.

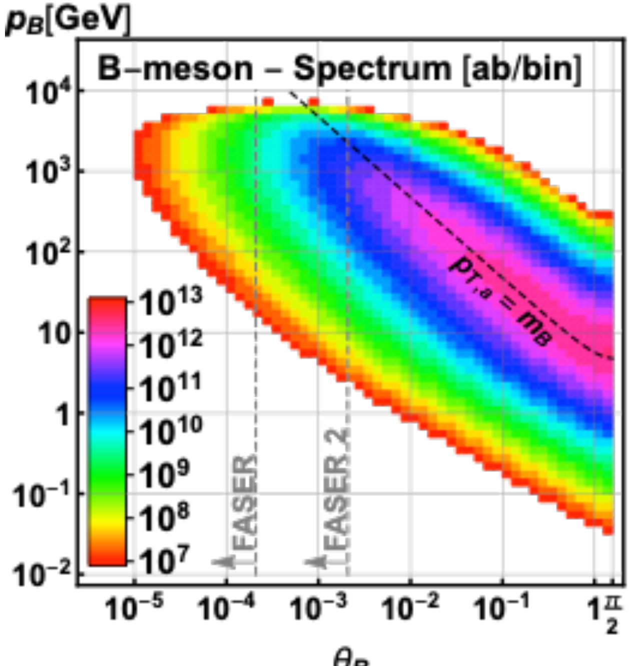
LHC can be a dark photon factory!

POSSIBLE FUTURE UPGRADE - FASER 2

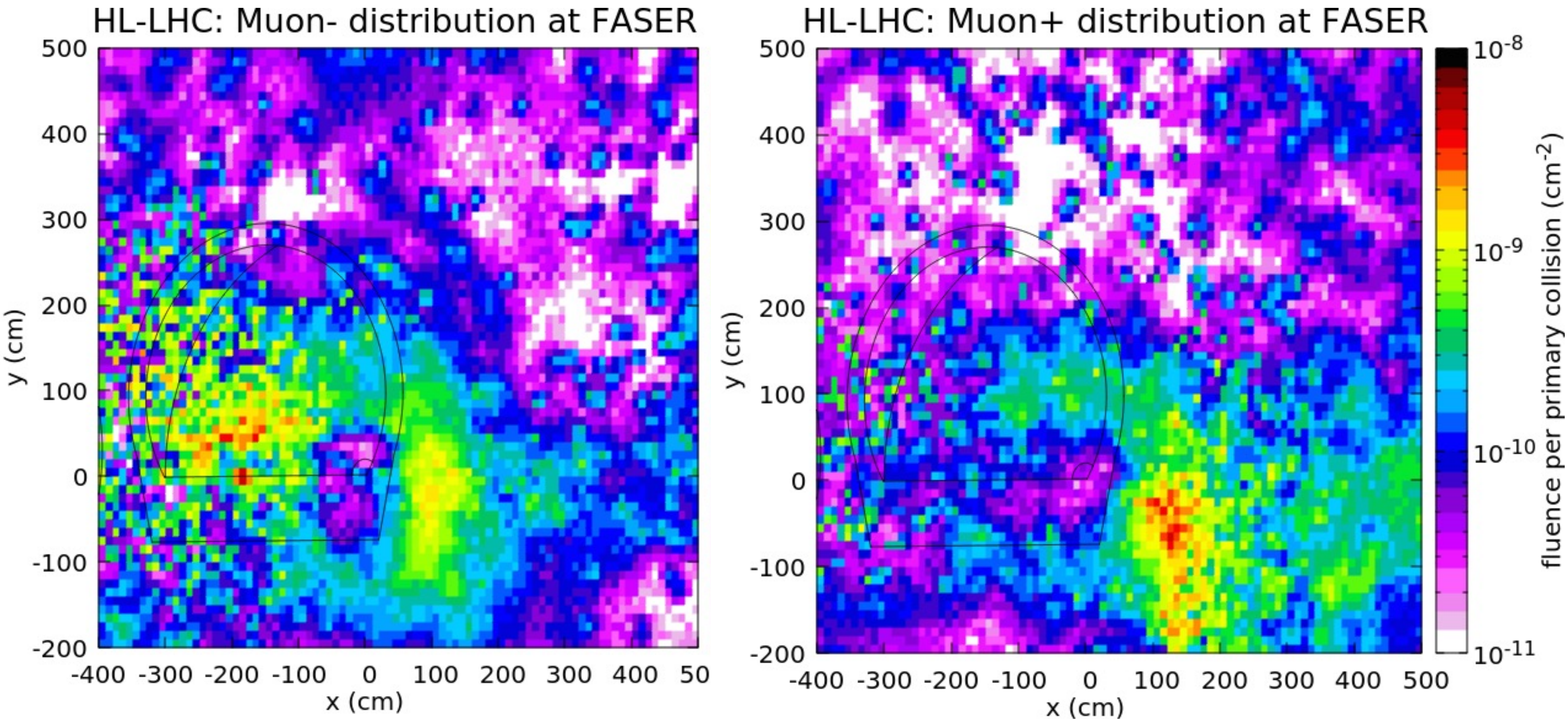
- A potential upgraded detector for HL-LHC running, would increase sensitivity further
- Increasing detector radius to 1m would allow sensitivity to new physics produced in heavy meson (B, D) decays increasing the physics case beyond just the increased luminosity



FASER 2 therefore becomes very strong compared to low energy experiments for certain models (dark Higgs), due to large B/D production rates at LHC: N_B/N_π~10^{-2} (~10^{-7} at beam dump expts)

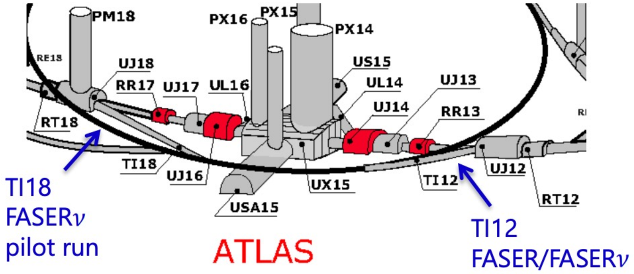


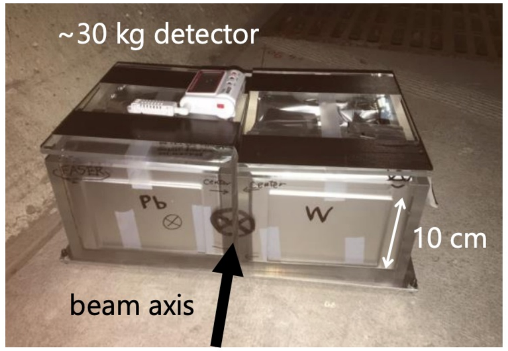
FLUKA distribution of muon flux in tranverse plane around LOS.
The flux is lowest on the LOS.

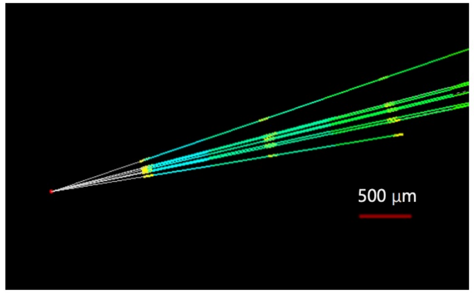


Pilot run in 2018 (LHC Run-2)

Aiming to demonstrate neutrino detection at the LHC for the first time





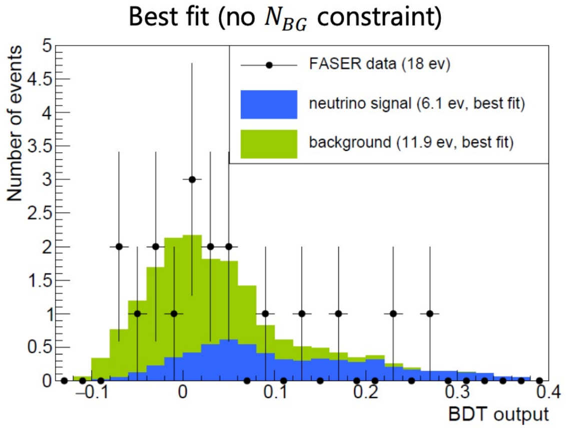


- Aims: charged particle flux measurement and neutrino detection
- We performed measurements in the tunnels TI18 and TI12, 480 m from the ATLAS IP.
- For neutrino detection, a 30 kg emulsion detector was installed in TI18 and 12.2 fb^{-1} data was collected.

First neutrino interaction candidates at the LHC, arXiv:2105.06197

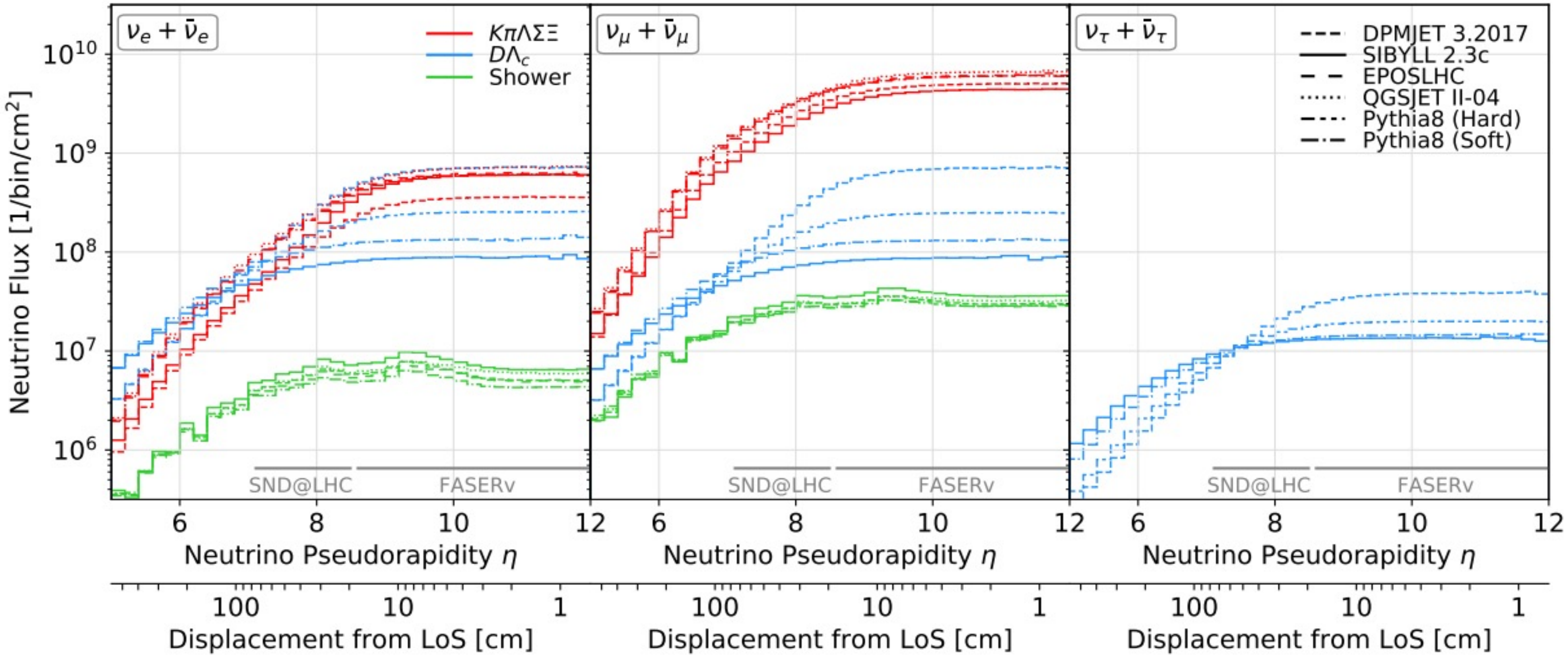
Results

- Analyzed target mass 11 kg
- 18 neutral vertices were selected
  - by applying # of charged particle ≥ 5, etc.
  - Expected signal $3.3^{+1.7}_{-0.9}$ events, BG 11.0 events
- In the BDT analysis, an excess of neutrino signal is observed. Statistical significance 2.7σ from null hypothesis
- This result demonstrates **detection of neutrinos at the LHC.**


Best fit (no N_{BG} constraint)

https://arxiv.org/pdf/2105.08270.pdf

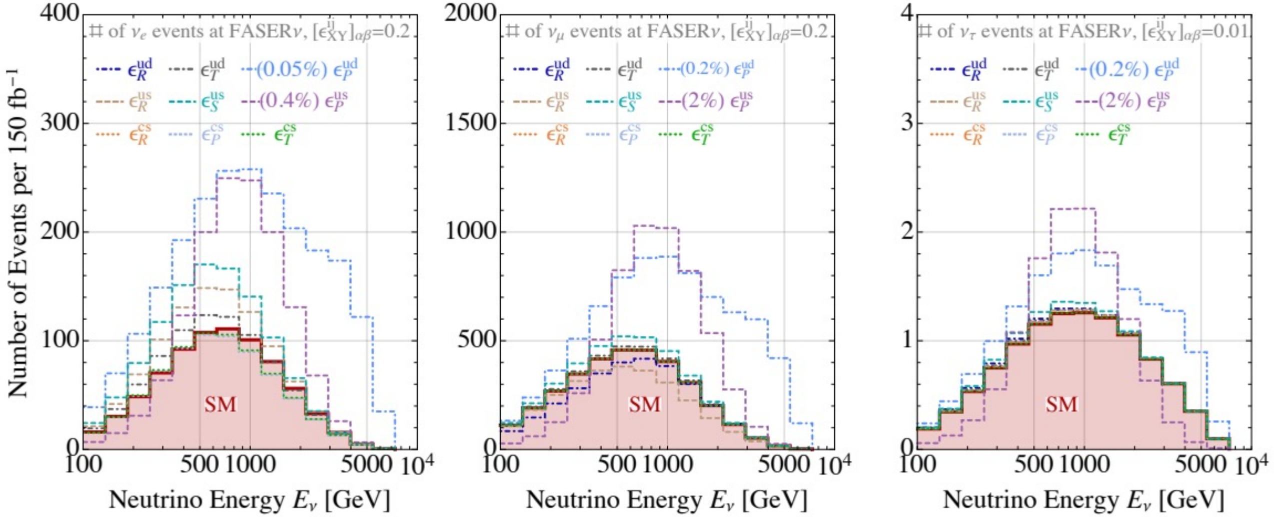
Neutrino flux falls off as you go away from the LOS.
Falls off most quickly for muon neutrinos (produced in pion decay), then electron neutrinos (produced in kaon decays) and slowest for tau neutrinos (from charm decay)

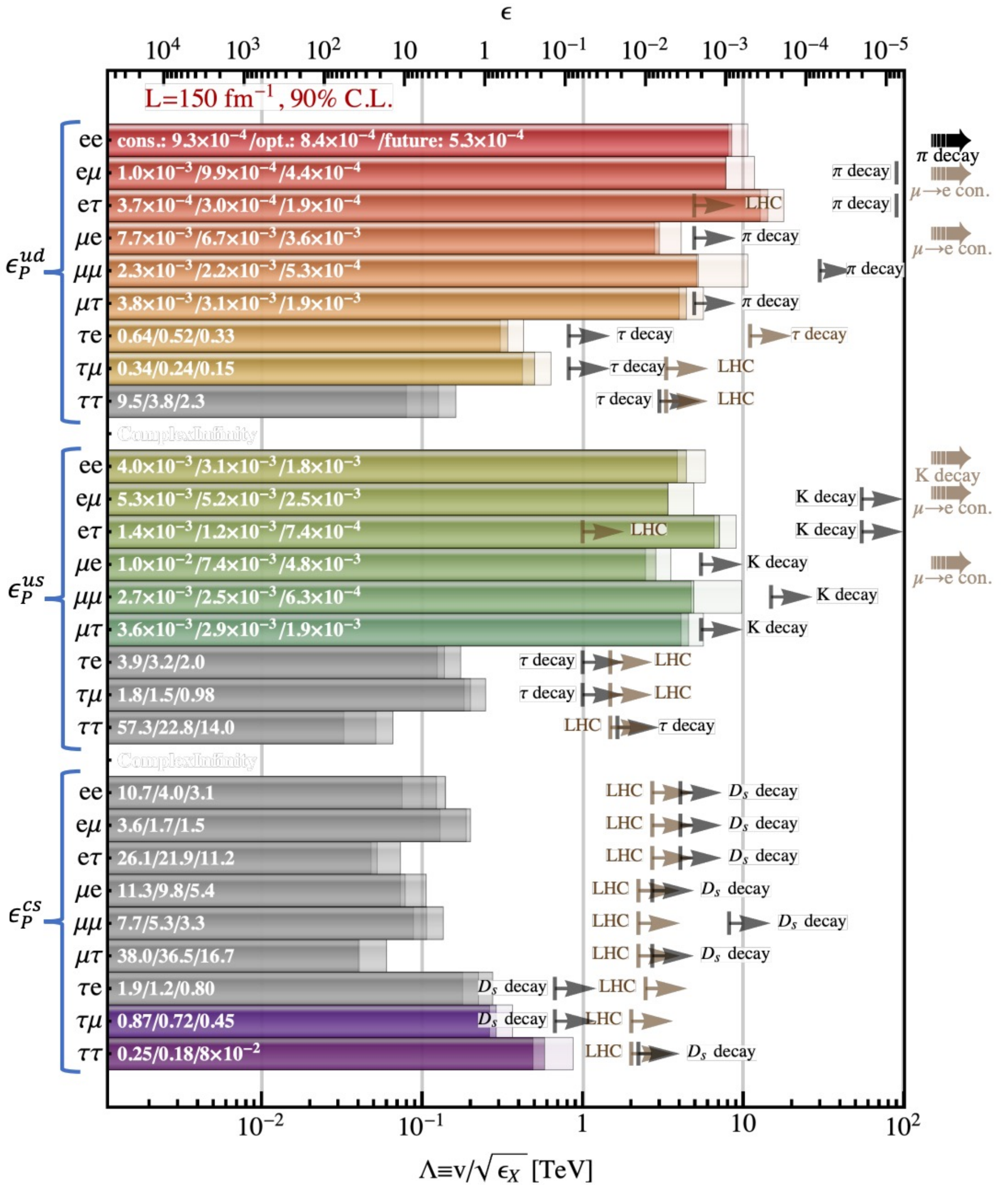


Some interest in having an off-axis neutrino detector to look at different production mechanisms.

https://arxiv.org/pdf/2105.12136.pdf

EFT with neutrinos





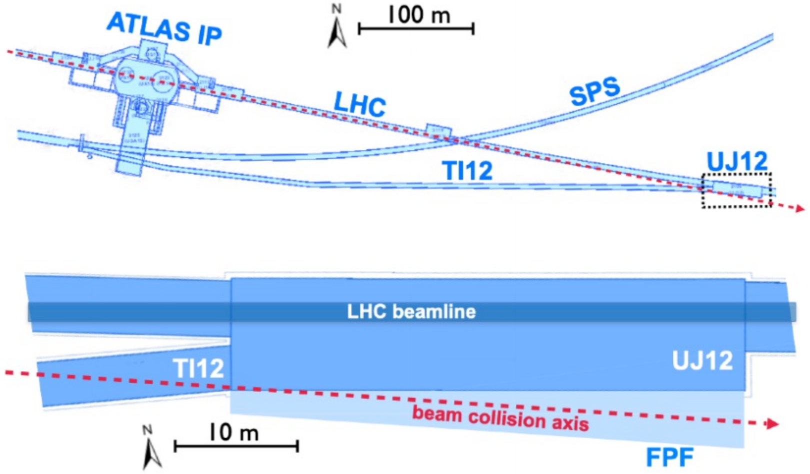
Compared to existing limits from other experiments, FASERν will, for a number of operators, reach similar sensitivities, showing that LHC neutrinos offer an interesting new way of probing physics beyond the Standard Model. Unlike other probes (meson decays, ATLAS and CMS analyses, etc.) a collider neutrino experiment like FASERν has the unique capability to identify the neutrino flavor. This is crucial complementary information in case excesses are found elsewhere in the future. Moreover, it allows to lift parameter degeneracies that may affect the interpretation of other measurements. One can, for instance, imagine a situation where different new physics effects with different signs conspire to leave a given meson or τ decay branching ratio unchanged compared to the SM, but change the flavor of the emitted neutrinos. Only a neutrino detector like FASERν would be able to uncover such a conspiracy.

Moving miliQan (scintillator based milicharged particle experiment) to FPF gives a big increase in sensitivity…

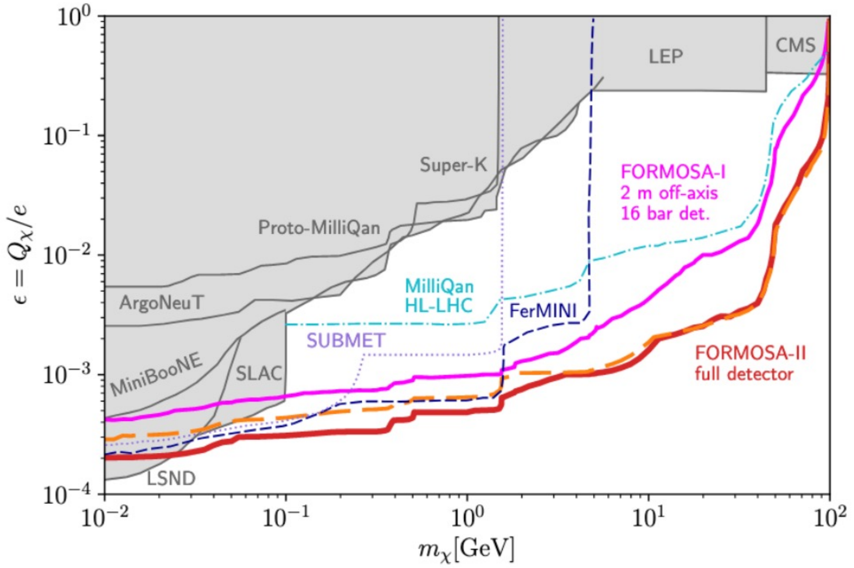
(this idea is called FORMOSA)

Alternative location?

- FORMOSA proposal: forward detector in FPF or UJ12 could see up to factor ~ 250 higher rate compared to central location
- Challenge: through-going muon rate > ~**1Hz/cm²**



- Beam muons provide significant challenges to trigger and background rejection (from after pulses) - is a detector feasible in this location?
- Exploring possibility (with FASER) to study forward backgrounds with Run 2 milliQan demonstrator in UJ12 (will otherwise be decommissioned)



https://arxiv.org/abs/2010.07941 (S. Foroughi-Abari, F. Kling, Y. Tsai)

Cost breakdown compared to HL-LHC works

Rough comparison of cost breakdown with HL-LHC works (assuming FPF total cost is 40MCHF).
Clear that CV is more expensive and EL is less expensive than corresponding HL-LHC works fraction.

Infrastructures	**[% of WP17]**	**% for FPF costing**
Civil engineering	67	25/40 = 63.5
Electrical distribution	13	0.7/40 = 1.8
Cooling & ventilation	12	7./40 = 17.5
Alarm & access system	2.4	2.5/40 = 6.3
Handling equipment	2.2	1.5/40 = 3.8
Operational safety	1.6	
Logistics & storage	1.4	
Technical monitoring	0.6	

This is based on 25MCHF for pure CE, and 15MCHF for services

K. Balazs, J. Osborne

UJ12 Alcoves – Very Preliminary Cost Estimate for CE works

Preliminary Cost Estimate

Ref.	Description of works	Cost [CHF]
1.	**CE Works Alcoves**	**10,866,870**
1.1	Alcove 6.4*2.9 m	2,864,902
1.2	Alcove 6.4*3.7 m	3,655,220
1.3	Alcove 6.4*4.4 m	4,346,748
2.	**Engineering and consultancy**	**1,630,031**
3.	**Minor Works**	**287,281**
3.1	Site investigation	74,524
3.2	Miscellaneous	212,757
Total Cost		**12,784,182**

Methodology

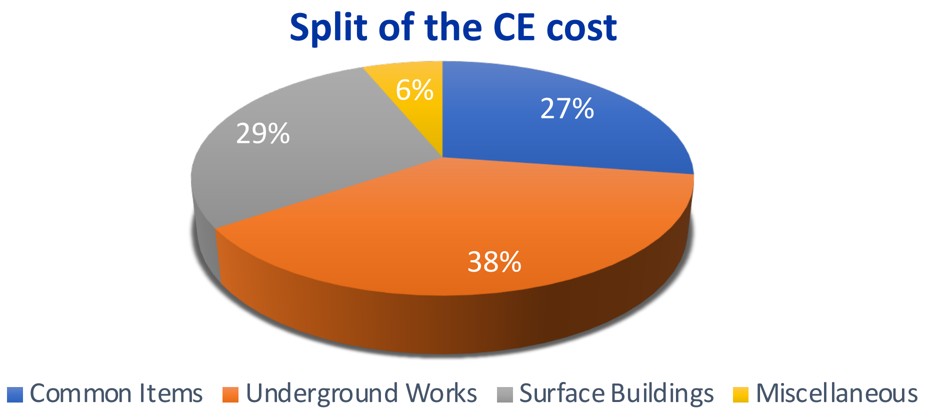
- Comparative Costing
- SPS Dump Facility Tunnel eye enlargement as reference point
- Cost Estimate Class 4 – total could be 50% higher and 30% lower than the given estimate

Assumptions

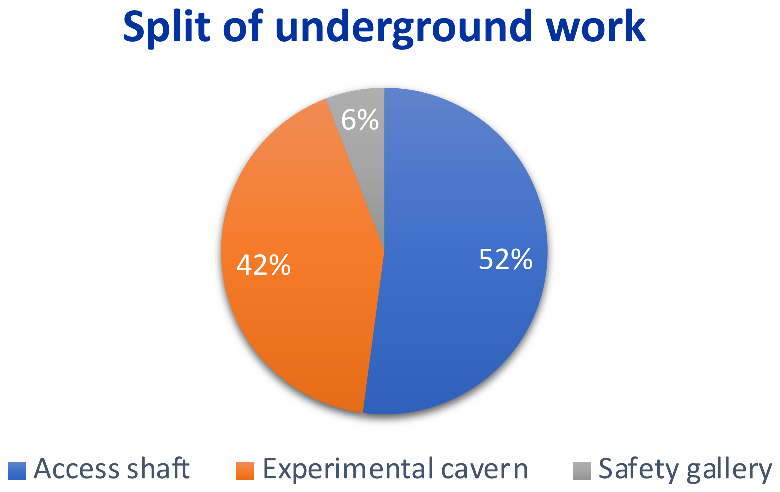
- Removal of the existing services and equipment from the UJ12 not included
- Services (CV, electricity etc.) not included

New Cavern – Very Preliminary Cost Estimate for CE

Ref.	Description of works	Cost [CHF]
1	**Common Items**	**6,356,824**
1.1	Contractual requirements (performance guarantee, insurances)	163,473
1.2	Specified requirements (Installation of barracks, Access road, Services etc.)	1,055,263
1..3	Method-related charges (Accommodations, Services, Site supervision, Project drawings)	5,054,772
1.4	Provisional sums	83,316
2	**Underground Works**	**8,859,608**
2.1	Site installation and equipment	3,689,097
2.2	Underground works	5,170,511
3	**Surface Buildings**	**6,598,589**
3.1	Generality	636,485
3.2	Top soils and Earthworks	882,051
3.3	Roads and Network	850,725
3.4	Buildings	4,229,328
4	**Miscellaneous**	**1,436,656**
4.1	Site investigation prior works	200,000
4.2	Project Management	1,236,656
	TOTAL CE WORKS	**23,251,677**



Split of the CE cost

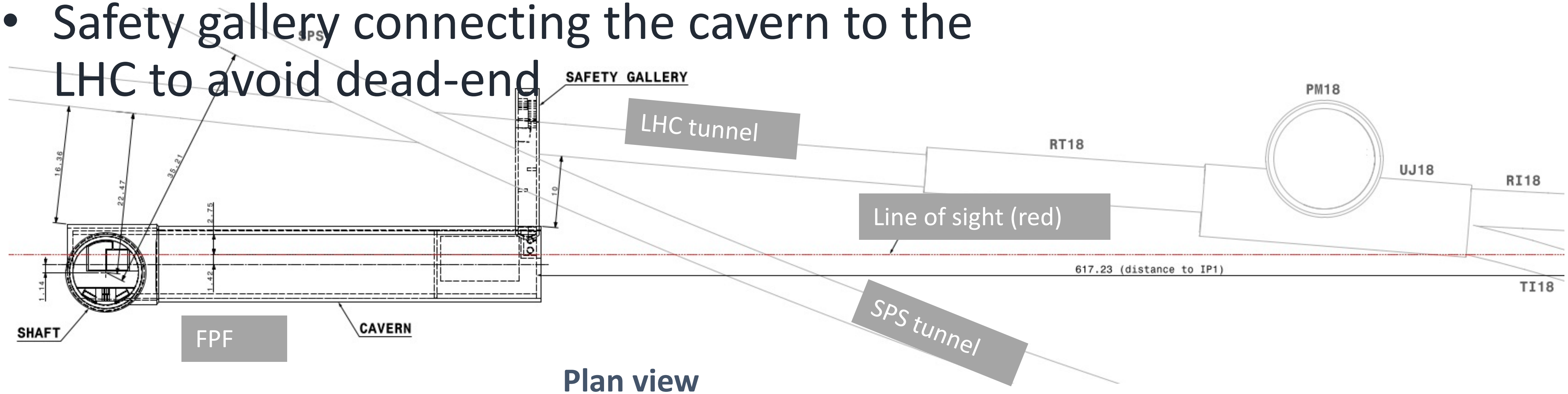


Split of underground work

K. Balazs, J. Osborne

Option 2 – Purpose built facility

- Proposed Layout
- 65 m long Experimental Cavern located on the LoS, approx. 612 m from IP1
- 9.1 m access shaft located on the top of the cavern
- Safety gallery connecting the cavern to the LHC to avoid dead-end

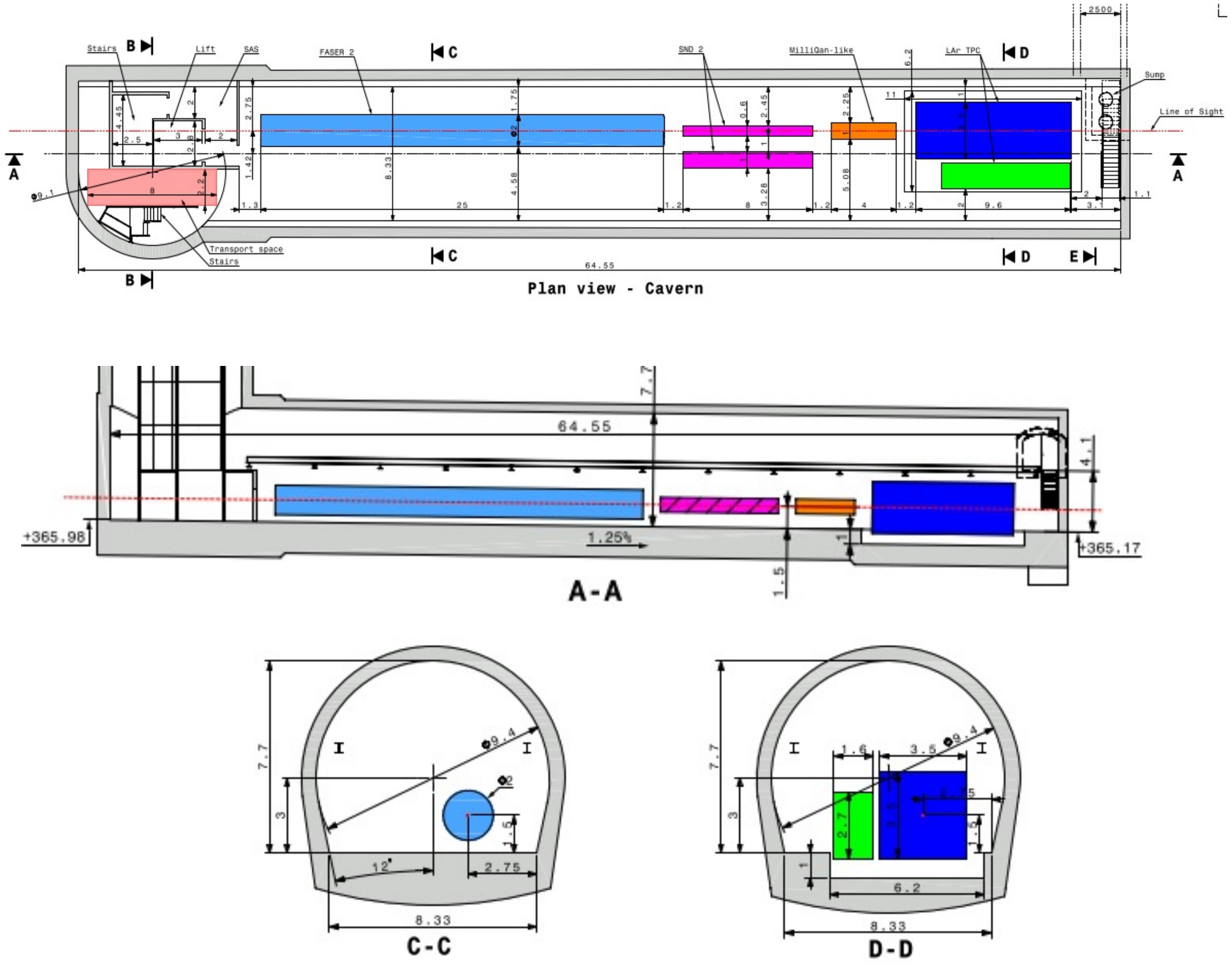


Plan view

K. Balazs, J. Osborne

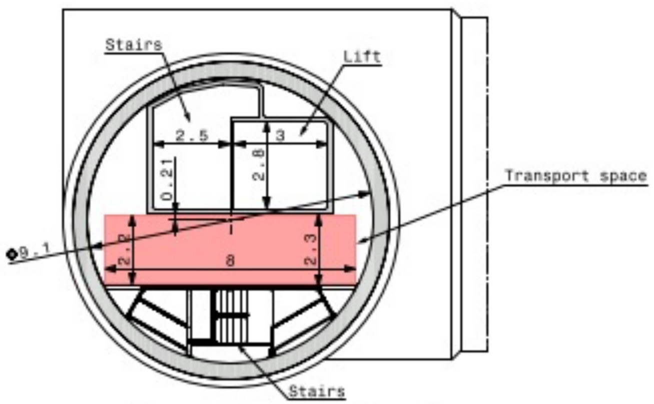
Option 2 – Underground structures

- 9.7 m wide cavern to allow access for transport and siting of some services
- Experiments centralised on the line of sight, 1.5m above the floor
- Floor parallel to the LoS, 1.25%fall
- Trench under the LAr detector to catch any escaped cold gas
- Concept based on overhead crane serving experiments along cavern length

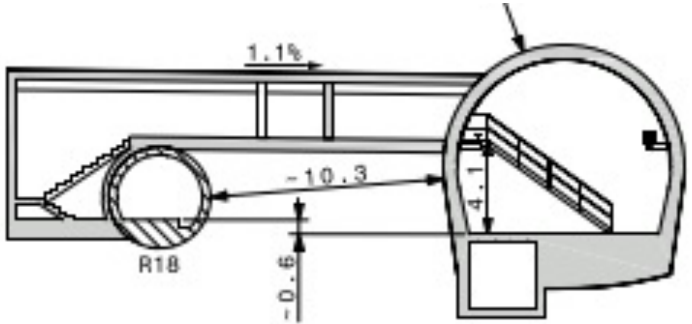


Option 2 – Underground structures

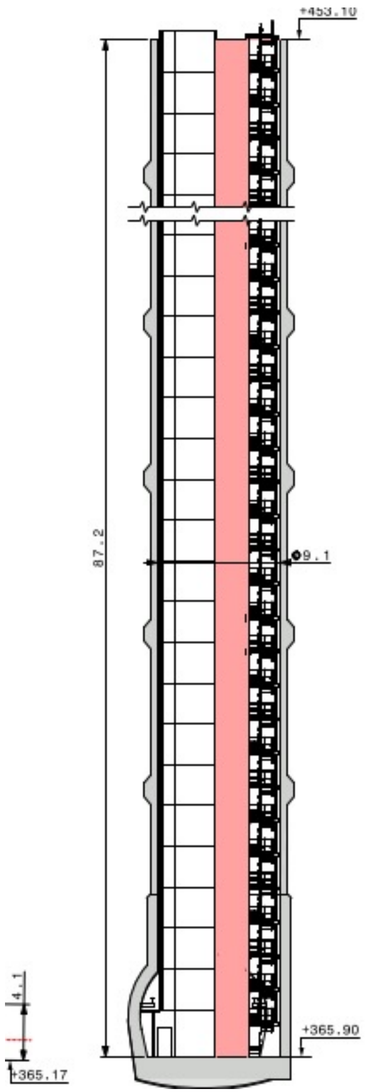
- 88m deep shaft includes lift and stairs for access and space reserved for transport
- Safety gallery connected to the LHC as per Safety requirements
- Ongoing discussions with the HE and RP department



Plan view shaft



Section through the new cavern and the safety gallery

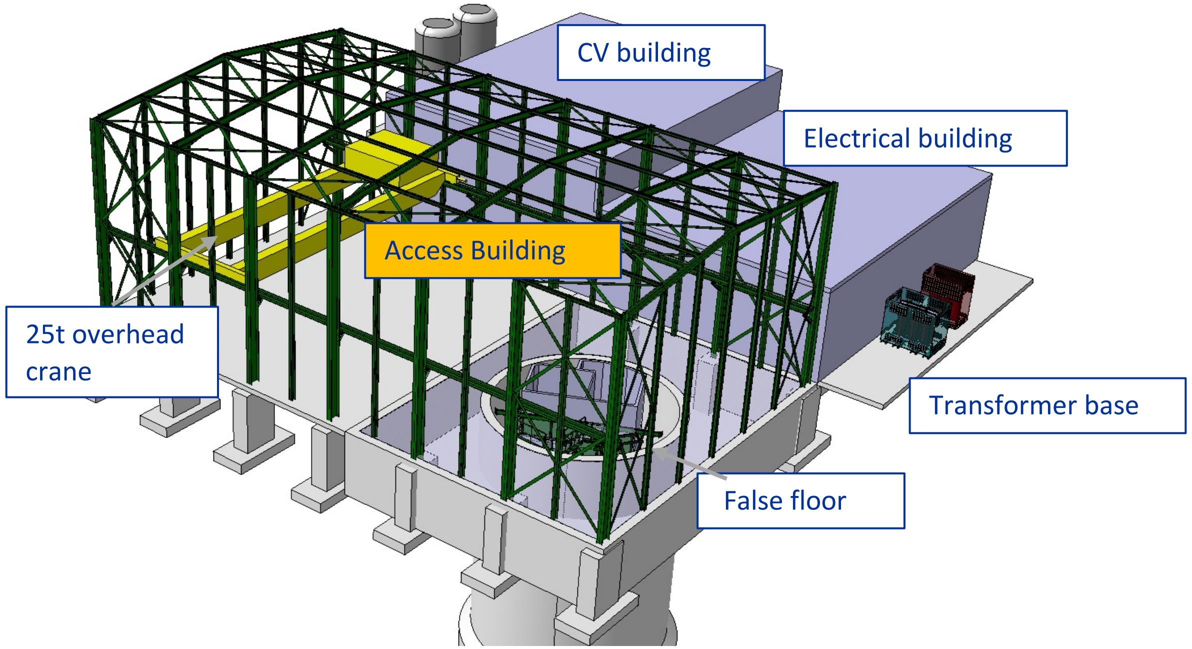


Cross section through the shaft

K. Balazs, J. Osborne

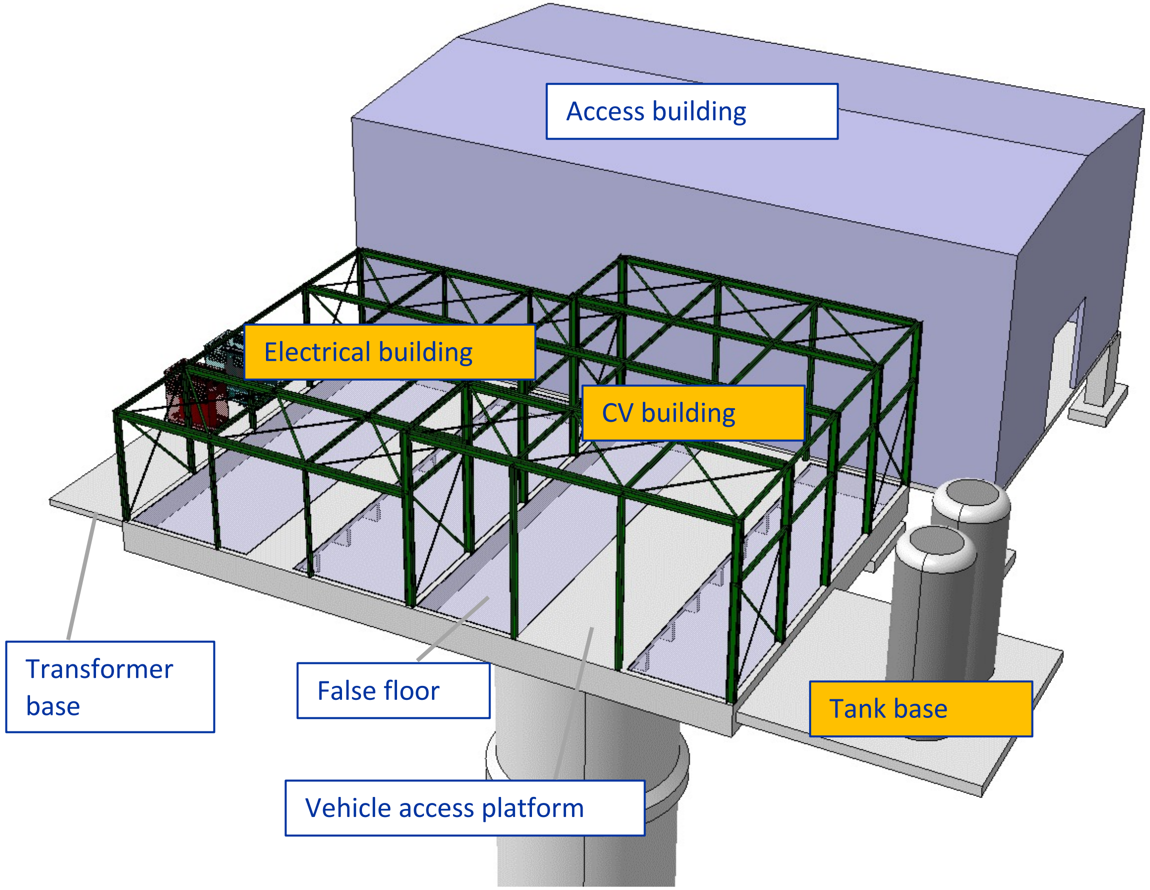
Option 2 – Surface buildings

- Access building
- Similar in size to SD1 and SD17
- Steel portal frame structure with concrete ground bearing floor
- 2.5 m deep false floor surrounding the shaft
- 25t overhead crane to lower the experiments to the floor level of the cavern



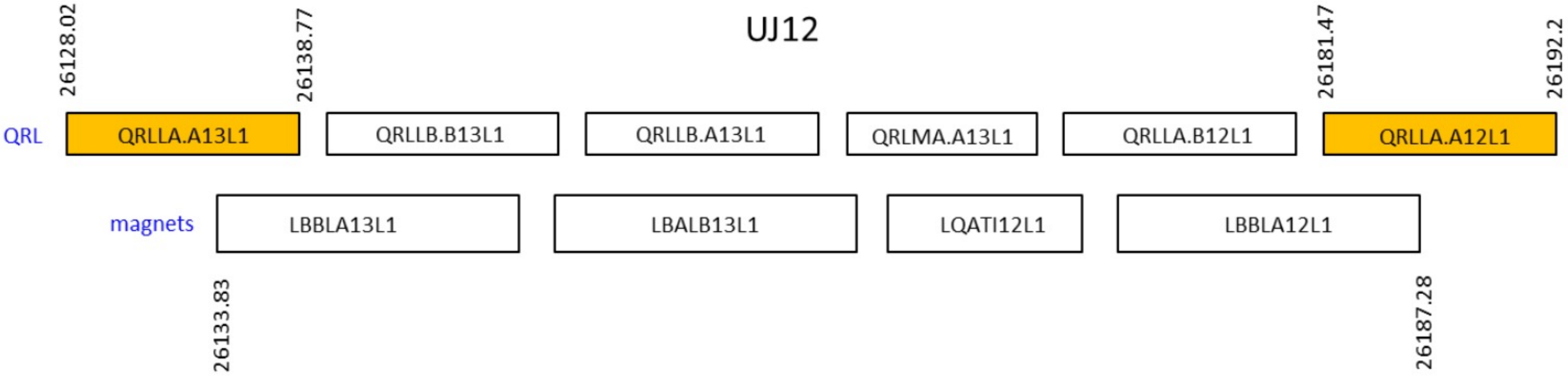
Option 2 – Surface buildings

- **Service Buildings**
- Electrical, cooling and ventilation building adjacent to the access building
- Electrical building designed as a steel frame structure
- Similar size to HL-LHC point 1
- 1.2m deep false floor to allow the services to be distributed into the shaft with a concrete access platform for vehicles to enter the buildings



S. Le Naour (LHC magnets) & K. Brodzinski (Cryo)

What needs to be removed from UJ12 for alcoves option



UJ12

26128.02

26138.77

26181.47

26192.2

QRL

QRLLA.A13L1

QRLLB.B13L1

QRLLB.A13L1

QRLMA.A13L1

QRLLA.B12L1

QRLLA.A12L1

magnets

LBBLA13L1

LBALB13L1

LQATI12L1

LBBLA12L1

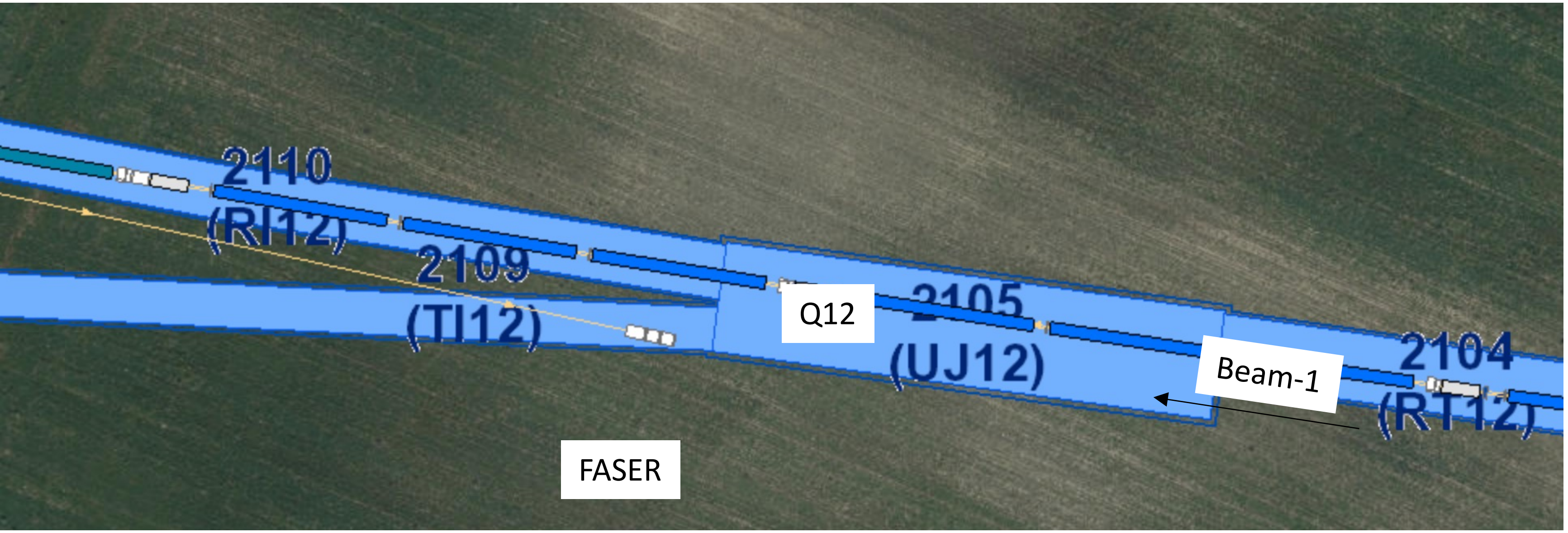
26133.83

26187.28

Figure 1; Sketch of UJ12 machine layout (magnets and the QRL) with main Dcum values.

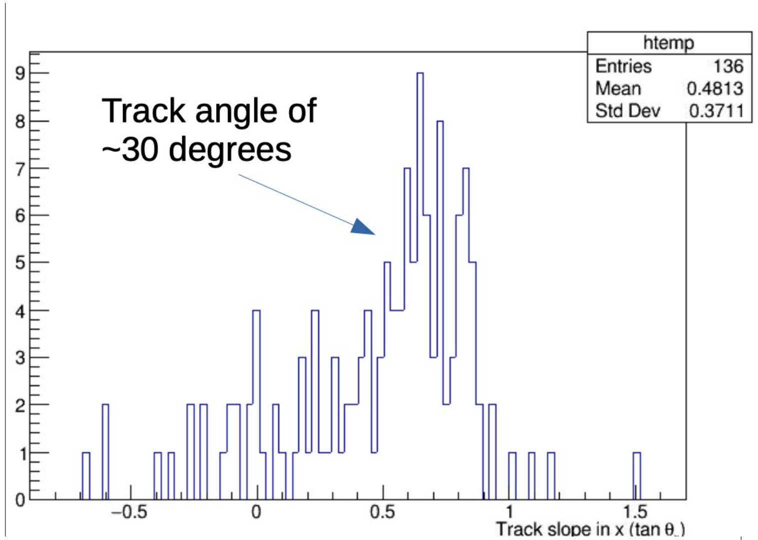
Beam background

- Data from pilot beam shows activity in calorimeter and pre-shower scintillators in time with beam-1 bunches passing FASER (beam-1 going towards ATLAS)
- Some events with this timing have tracks in the back tracker station consistent with particles coming from around the Q12 magnet in the LHC beamline close to FASER (angle of ~30-40degrees)
- As reported in the FASER TP an emulsion detector installed in TI12 in 2018 LHC running, observed a small secondary peak in the angle of charged particles that was consistent with particles coming from Q12
- Overall normalized beam losses in the pilot run were ~x10 larger than in LHC physics running (mostly due to low energy beam, and not fully optimized optics and collimator settings)
- Suggests that this background would add a few 10s of Hz of triggers in FASER physics running (at 2e34cm^{-2}s^{-1})

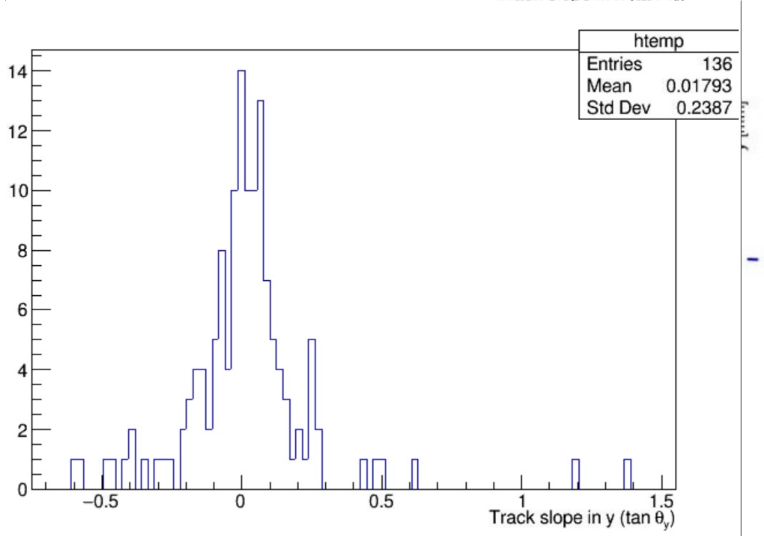


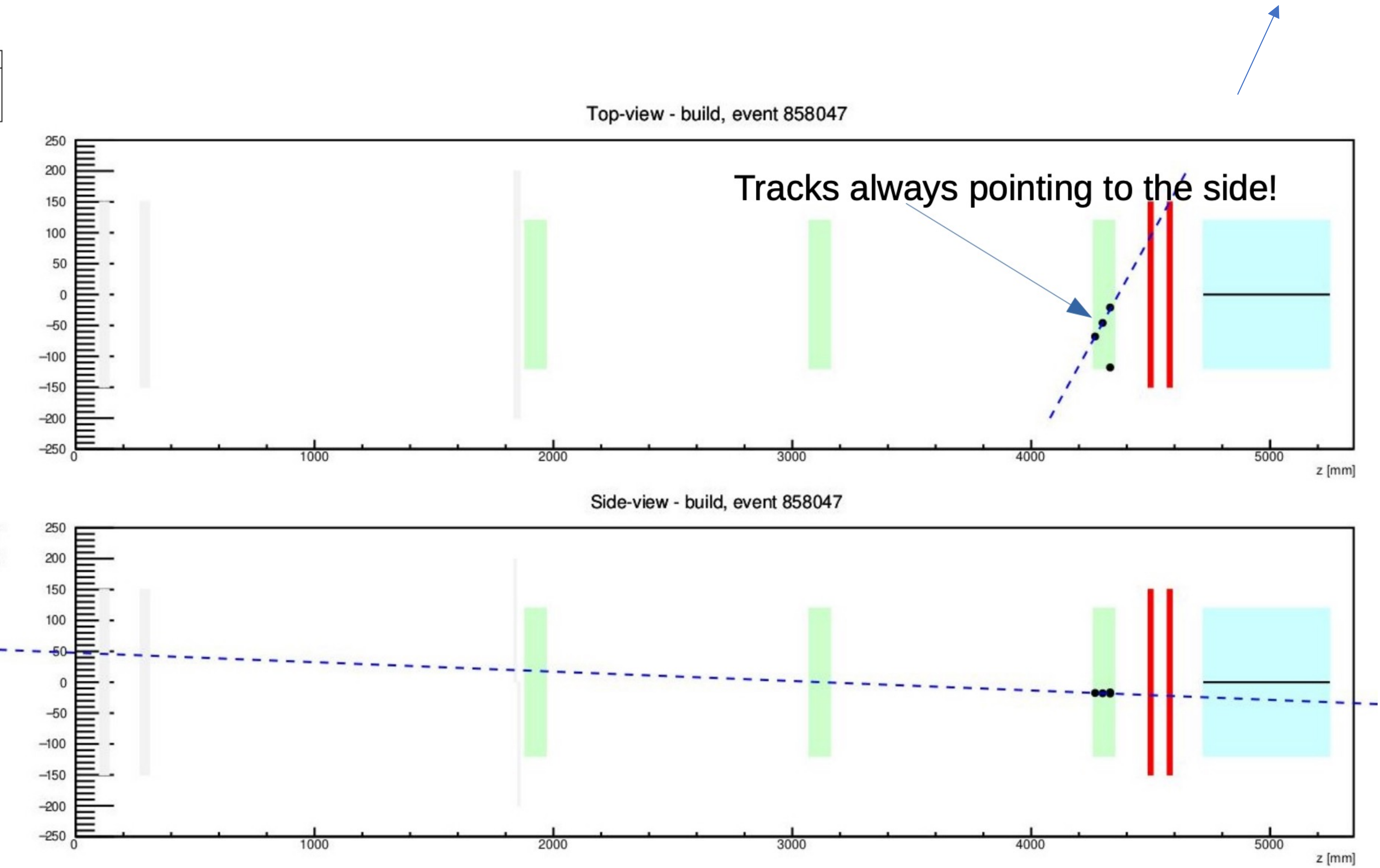
Tracks for beam-1 background events

To Q12



Track angle of ~30 degrees

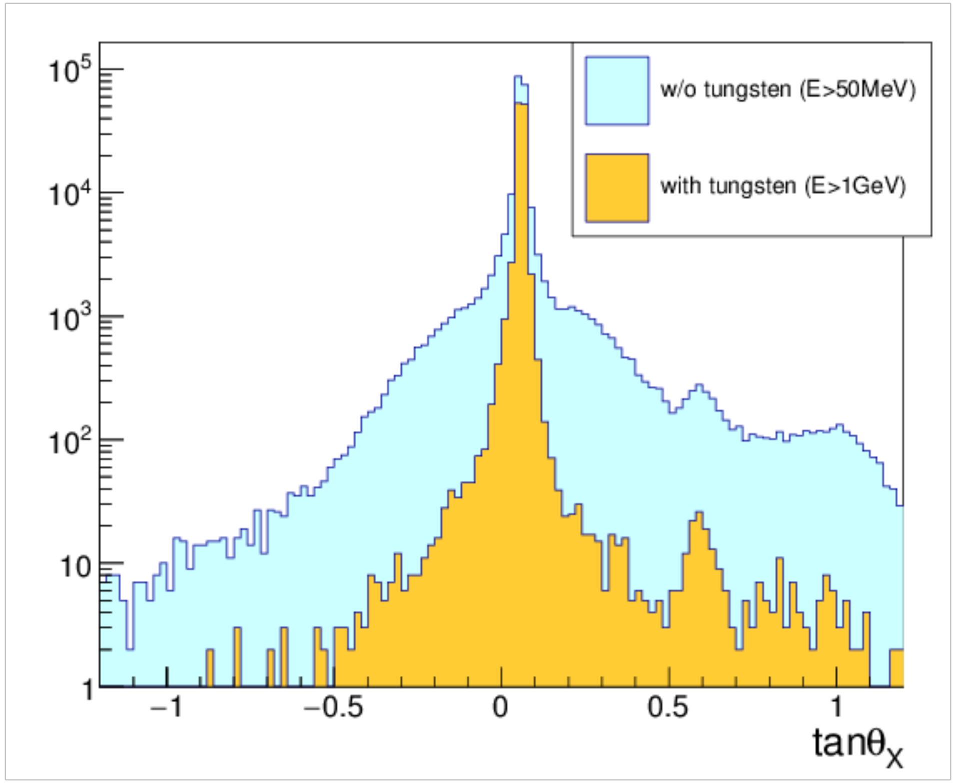


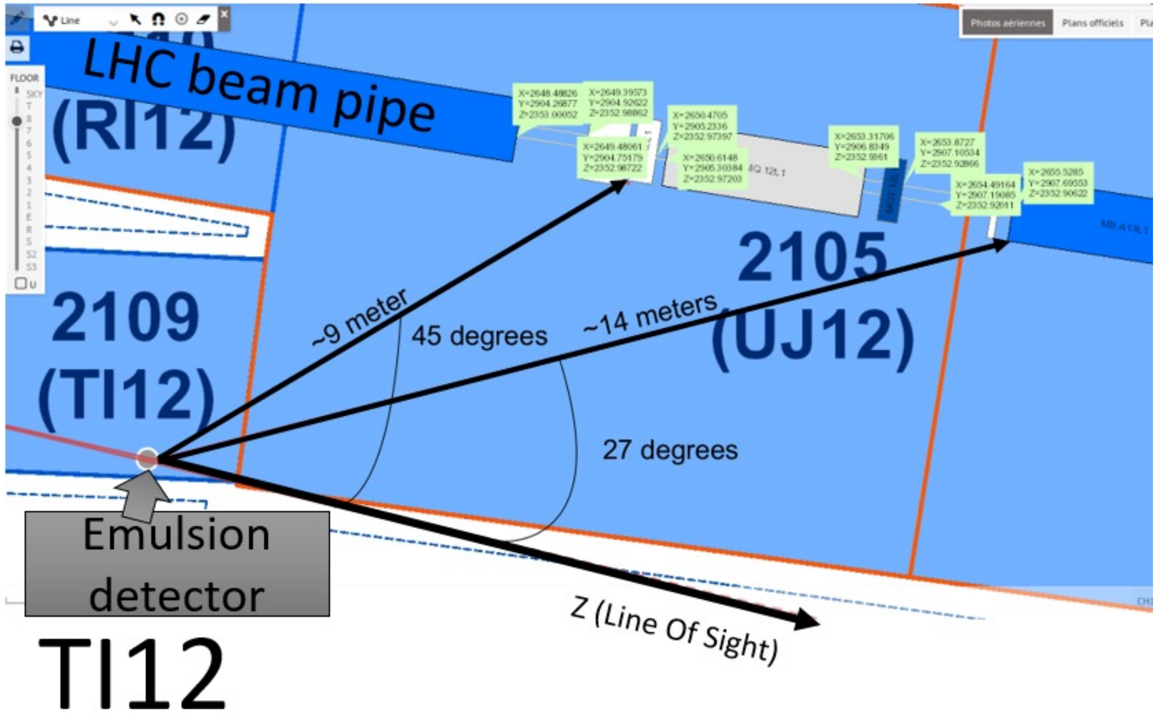


Tracks always pointing to the side!

Beam background in 2018 running

Figures from FASER Technical Proposal.
The plot on the left is showing the results of the emulsion detector installed in TI12 in 2018 LHC running.
The main peak shows muons coming along the LOS from the ATLAS IP.
The secondary peak corresponds to an angle consistent with particles coming from Q12.





Neutrinos at the FPF

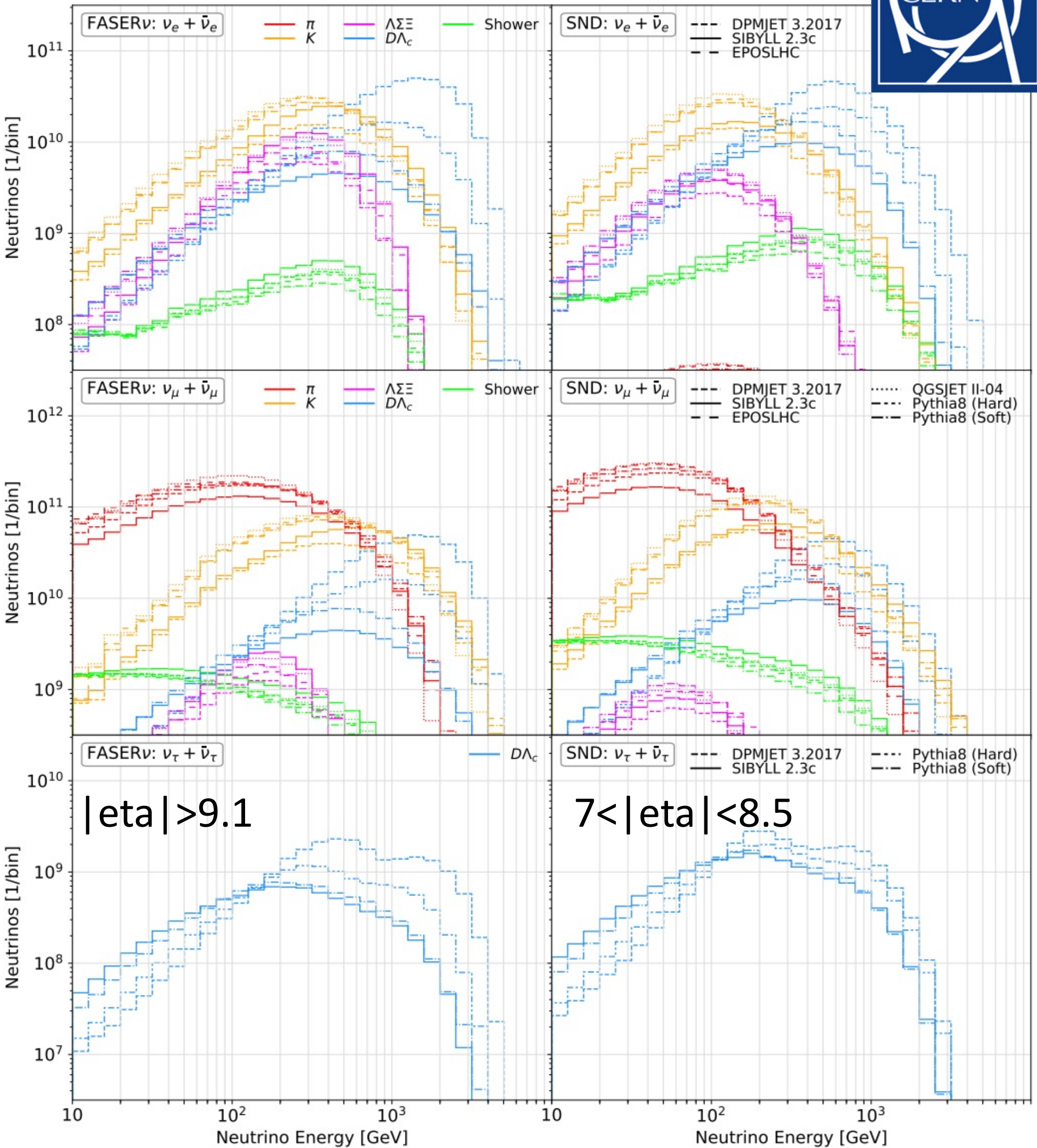
https://arxiv.org/pdf/2105.08270.pdf (F. Kling)

Neutrino production process energy and rapidity dependent.
Large uncertainties on expected rate especially from charm

Expected number of interactions in a 10tn detector centred on the LOS for the full HLC-LHC dataset. (Using SIBYLL generator – most pessimistic.)
Numbers can change due to transverse dimensions of detector (see backup)

Species	#evts (10tn, 3/ab)	
nu_e	64k	~100k
nubar_e	36k	
nu_mu	430k	~500k
nubar_mu	120k	
nu_tau	2k	~3k
nubar_tau	0.8k	

Typical energy of interacting neutrinos on LOS ~900 GeV much higher then most existing measurements

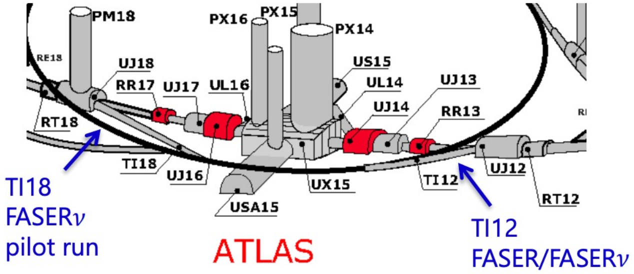


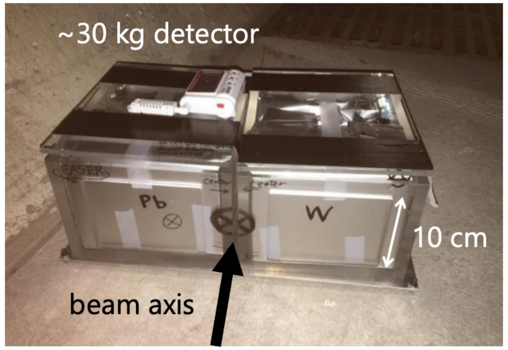
Production process rapidity dependent, can be used to constrain PDFs and production processes

Neutrinos at LHC (Run-2)

PRD.104.L091101

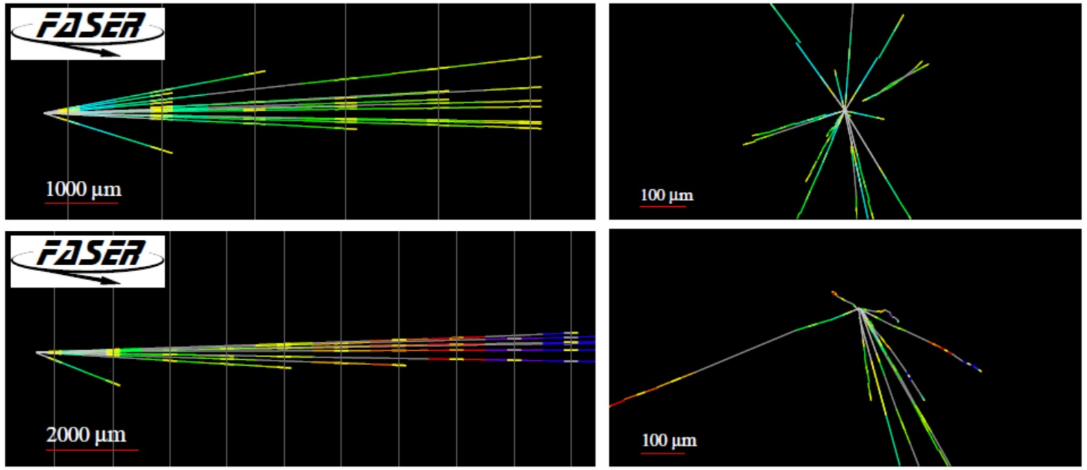
As part of the preparation of FASER, in 2018 LHC running we installed a small emulsion detector (30kg / 11kg fiducial) for 4 weeks, ~12/fb





First neutrino interaction candidates at the LHC, arXiv:2105.06197

Neutrino interaction candidates



arXiv:2105.06197v1 [hep-ex] 13 May 2021

UCI-TR-2021-04, KYUSHU-RCAPP-2020-04, CERN-EP-2021-087

First neutrino interaction candidates at the LHC

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(Dated: May 14, 2021)

FASERν at the CERN Large Hadron Collider (LHC) is designed to directly detect collider neutrinos for the first time and study their cross sections at TeV energies, where no such measurements currently exist. In 2018, a pilot detector employing emulsion films was installed in the far-forward region of ATLAS, 480 m from the interaction point, and collected 12.2 fb^{-1} of proton-proton collision data at a center-of-mass energy of 13 TeV. We describe the analysis of this pilot run data and the observation of the first neutrino interaction candidates at the LHC. This milestone paves the way for high-energy neutrino measurements at current and future colliders.

I. INTRODUCTION

There has been a longstanding interest in detecting neutrinos produced at colliders [1–6], but to date no collider neutrino has ever been directly detected. Proton-proton (pp) collisions at a center-of-mass energy of 14 TeV during LHC Run-3, with an expected integrated luminosity of 150 fb^{-1}, will produce a high-intensity beam of $\mathcal{O}(10^{12})$ neutrinos in the far-forward direction with mean interaction energy of about 1 TeV. FASERν [7] is designed to detect these neutrinos and study their prop-

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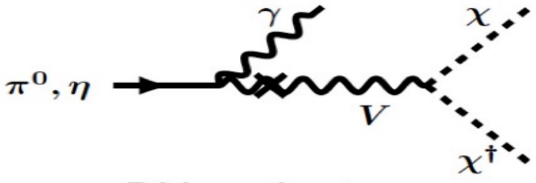
Highlights the potential of the forward LHC location for neutrino physics!

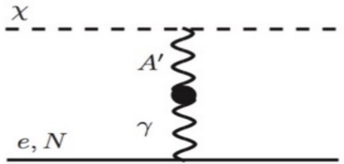
https://arxiv.org/abs/2107.00666 (B. Batell, J. L. Feng, A. Ismail, F. Kling, R. M. Abraham, S. Trojanowski)
https://arxiv.org/abs/2101.10338 (B. Batell, J. L. Feng, S. Trojanowski)

DM Scattering experiment in FPF

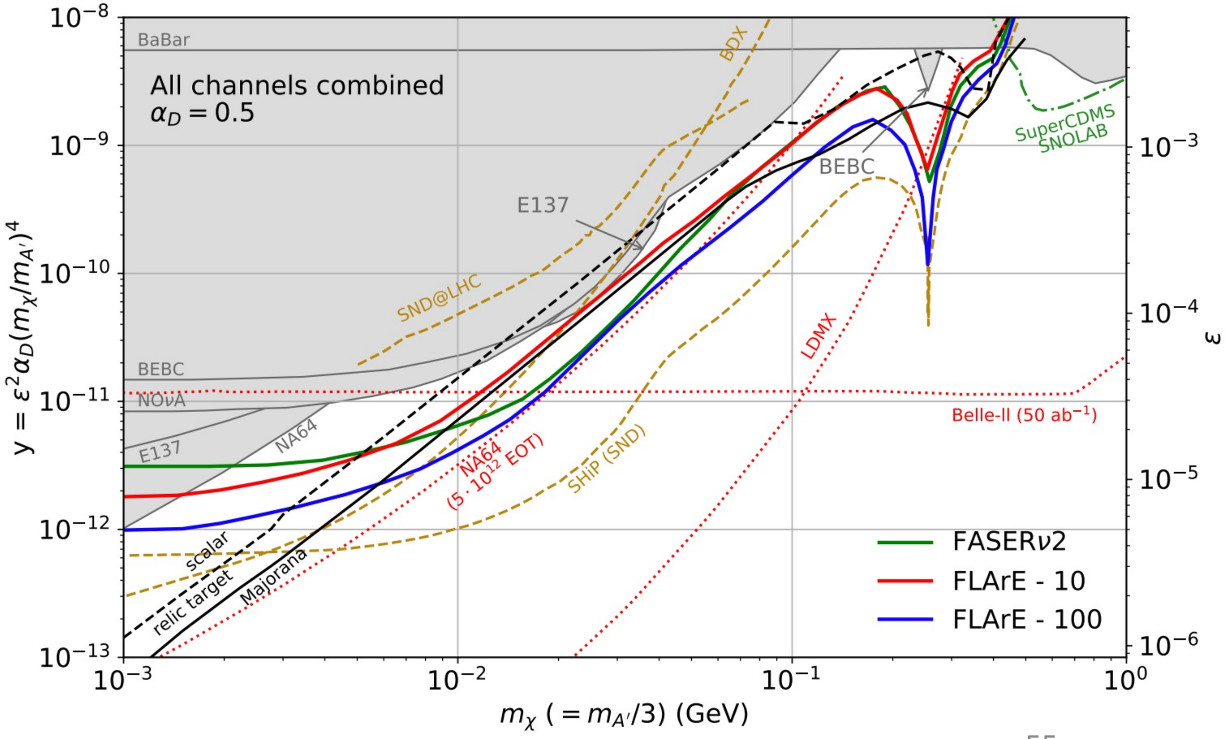
- Recent theory level studies looking at possible sensitivity to DM scattering in a LArTPC in the FPF (FLArE)
  - Consider both DM-electron and DM-nucleus scattering
- Very interesting sensitivity, probing the thermal relic region
- Claim neutrino background can be separated from DM signal using energy and angle cuts
  - Needs to be demonstrated with a more detailed analysis
- Opens door to direct-detection type DM search at the LHC



DM production

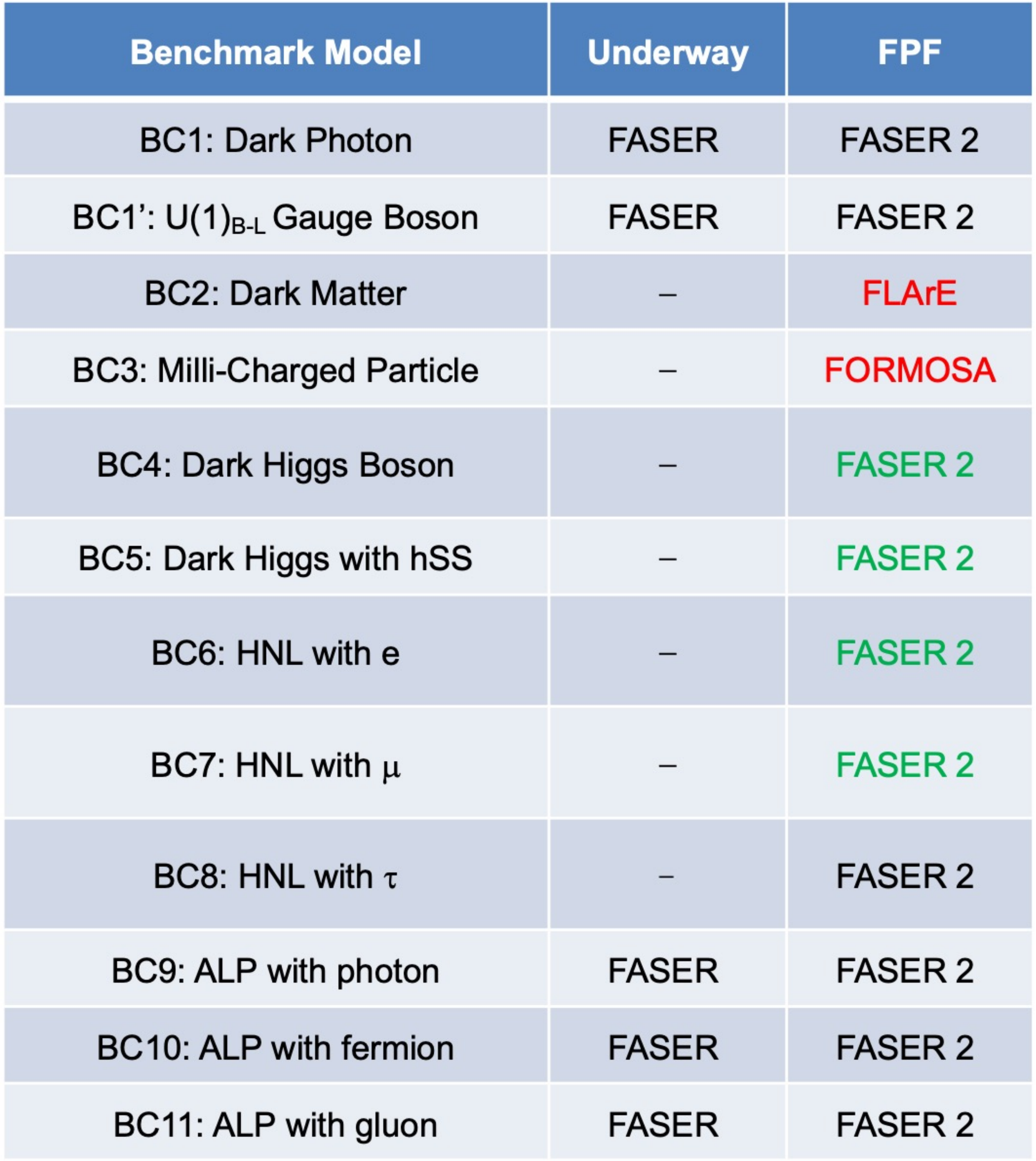


DM scattering



BSM at FPF

FPF experiments would give significant new sensitivity in all of the dark sector PBC benchmark models



Benchmark Model	Underway	FPF
BC1: Dark Photon	FASER	FASER 2
BC1’: $U(1)_{B\text{-}L}$ Gauge Boson	FASER	FASER 2
BC2: Dark Matter	–	FLArE
BC3: Milli-Charged Particle	–	FORMOSA
BC4: Dark Higgs Boson	–	FASER 2
BC5: Dark Higgs with hSS	–	FASER 2
BC6: HNL with e	–	FASER 2
BC7: HNL with μ	–	FASER 2
BC8: HNL with τ	–	FASER 2
BC9: ALP with photon	FASER	FASER 2
BC10: ALP with fermion	FASER	FASER 2
BC11: ALP with gluon	FASER	FASER 2