Run 3 Data and Implications for FPF Environment

FPF5 workshop

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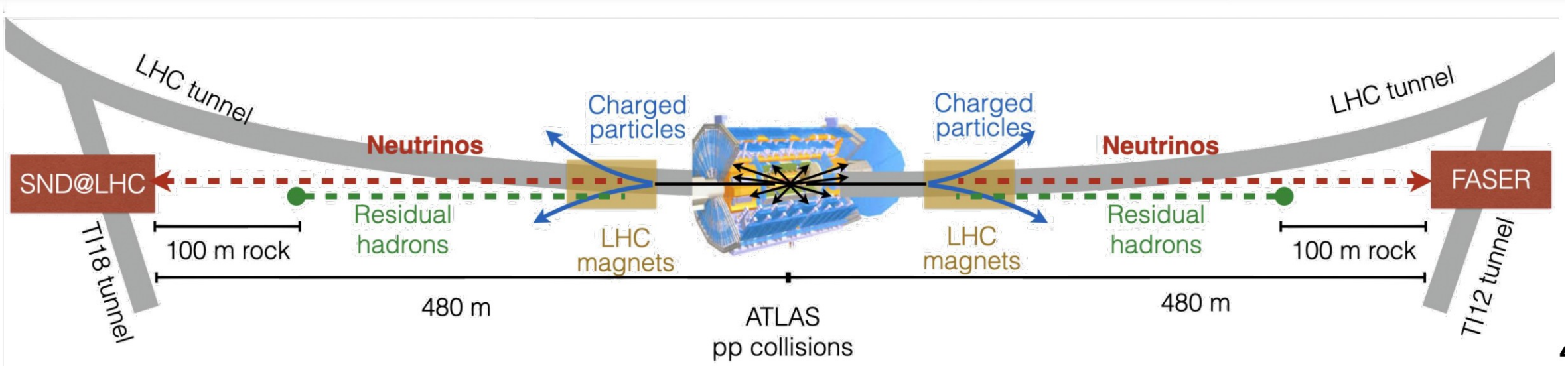
15/11/22

SND@LHC input provided by Antonia Di Crescenzo

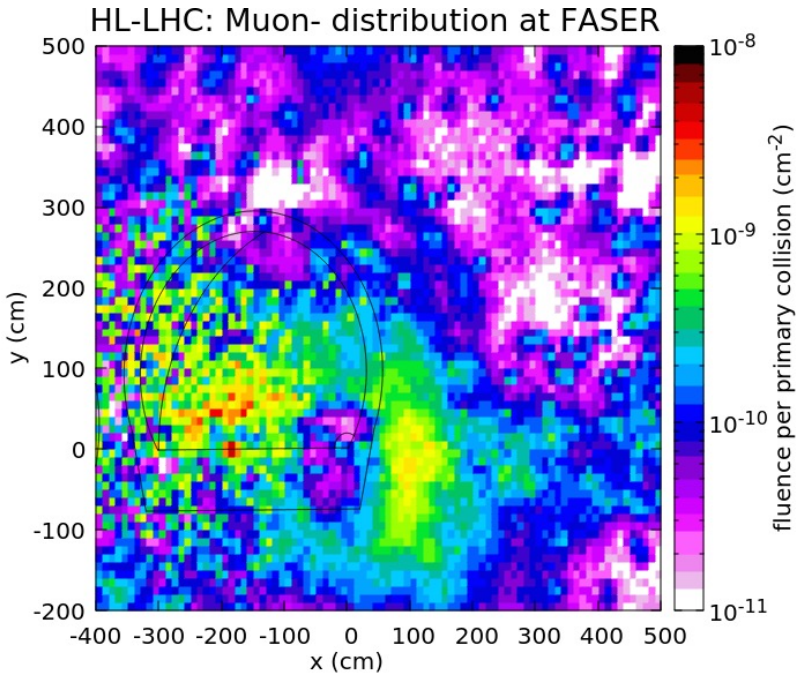
Introduction

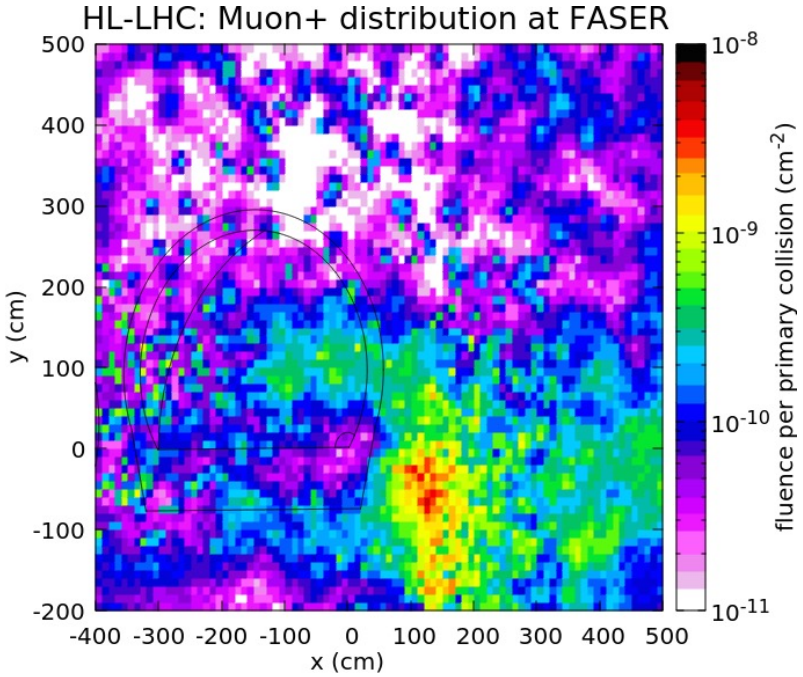
- FASER and SND@LHC experiments situated on, or very close-to the collision axis LOS of IP1 started taking data with the start of LHC Run 3 in July 2022
- First data from these experiments can provide important input on the expected background muon rate at the FPF
- In addition to FASER/SND@LHC data, the FASER collaboration also installed several small emulsion detectors around the LOS to measure muon rates further from the LOS
- Data shown in this talk are very preliminary, more detailed analysis is ongoing from both Collaborations
- Given that a lot of the Long Straight Section (magnets, absorbers, collimators) will change between Run 3 and HL-LHC, the Run 3 measurements may not apply directly to the FPF, but can provide important information to benchmark/validate FLUKA simulations



Pre Run-3 Simulations

FASER TP (1812.09139)



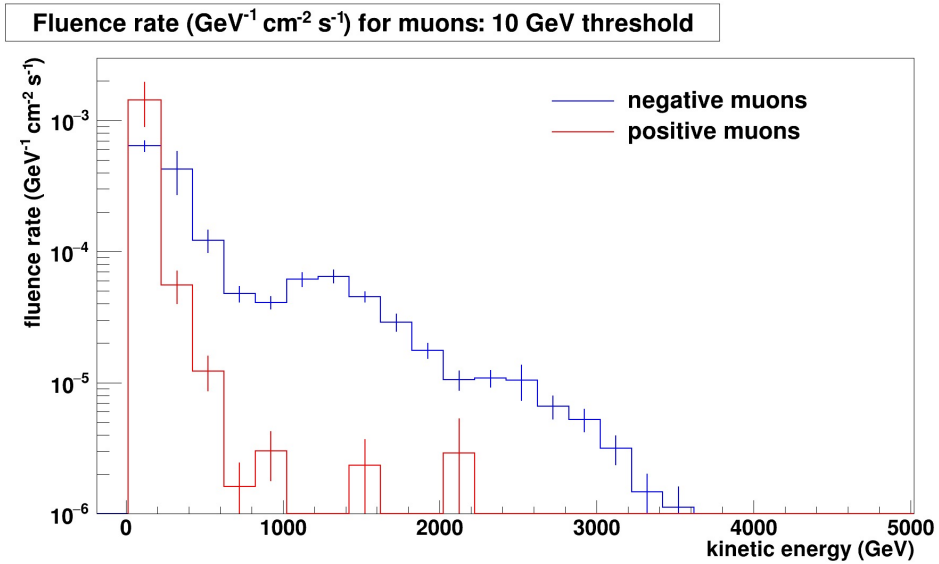


FLUKA simulations carried out by CERN STI group for FASER Technical Proposal.

Main messages:

- Rate ~0.5Hz/cm^2 @ 2e34cm^{-2}s^{-1}
- Low on LOS, increases by 1-2 orders of magnitude when going 1-2m away
- Difference rate/spectra for mu+/mu-

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



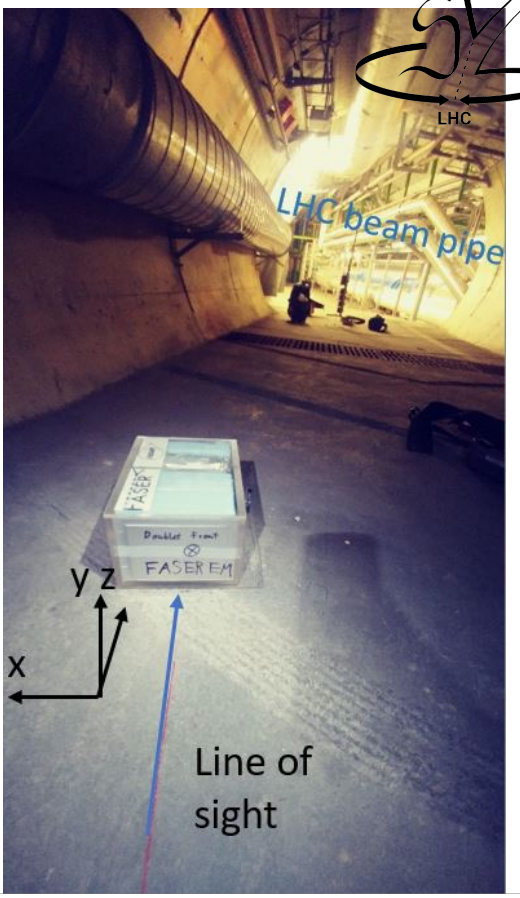
Pre Run-3 Measurements

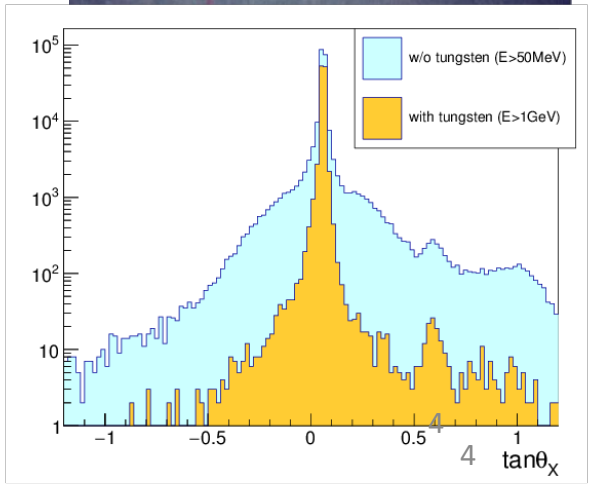
FASER TP (1812.09139)

	beam [fb^{-1}]	observed tracks [cm^{-2}]	efficiency	normalized flux, all [fb cm^{-2}]	normalized flux, main peak [fb cm^{-2}]
TI18	2.86	18407	0.25	$(2.6 \pm 0.7) \times 10^4$	$(1.2 \pm 0.4) \times 10^4$
TI12	7.07	174208	0.80	$(3.0 \pm 0.3) \times 10^4$	$(1.9 \pm 0.2) \times 10^4$
FLUKA simulation, E>100 GeV				1×10^4	

Flux measured in both TI12 and TI18 using small emulsion detectors installed in 2018 LHC running.
Measured rate consistent with FLUKA expectation.
Electronic detector (TimePixBLM) showed rate correlated with luminosity in IP1

Period	Luminosity [10^{34} s^{-1} cm^{-2}]	Counting Rate [s^{-1}]	Counting Rate/Luminosity [10^{-34} 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



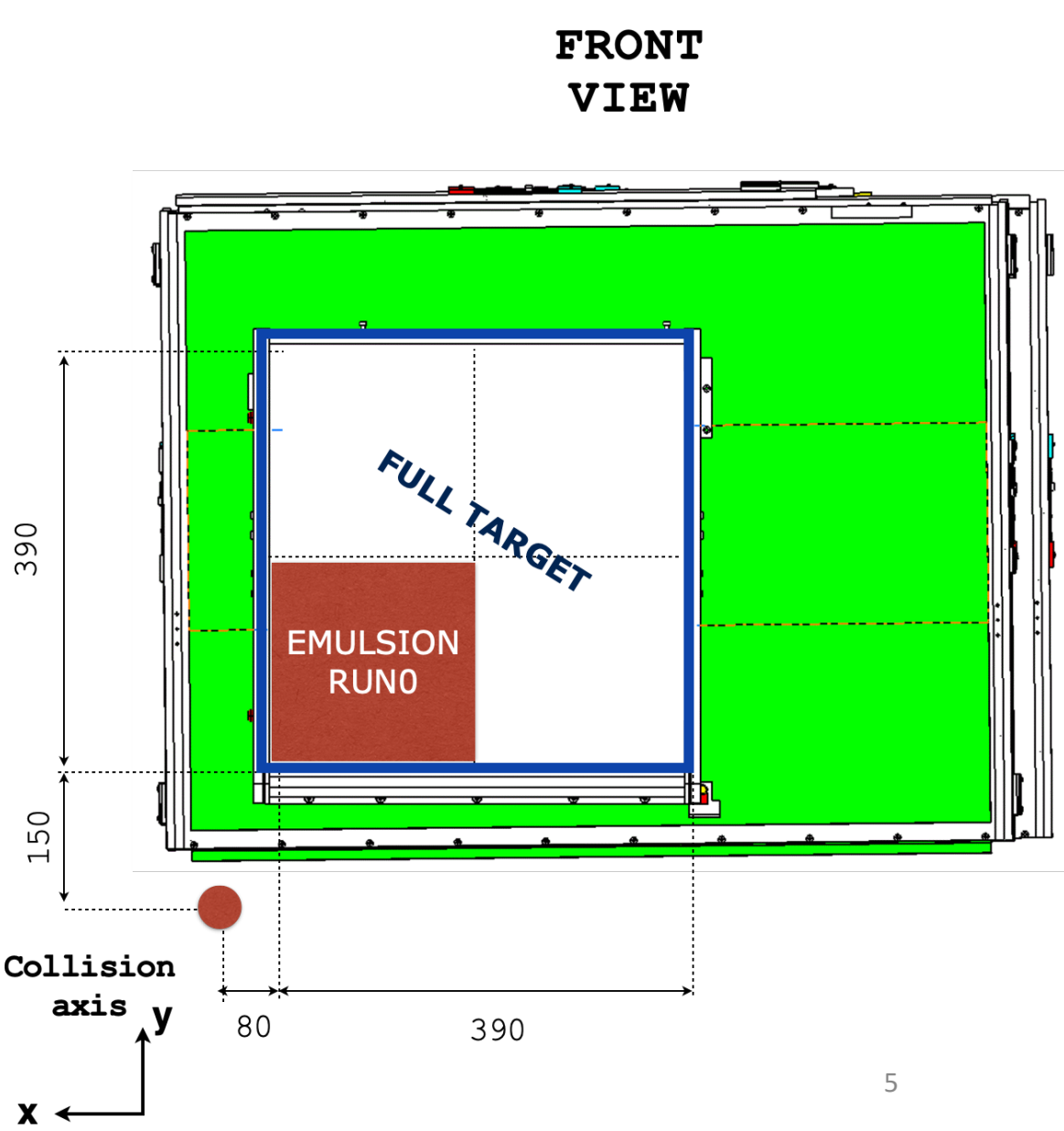


A reminder of Experiments Geometry

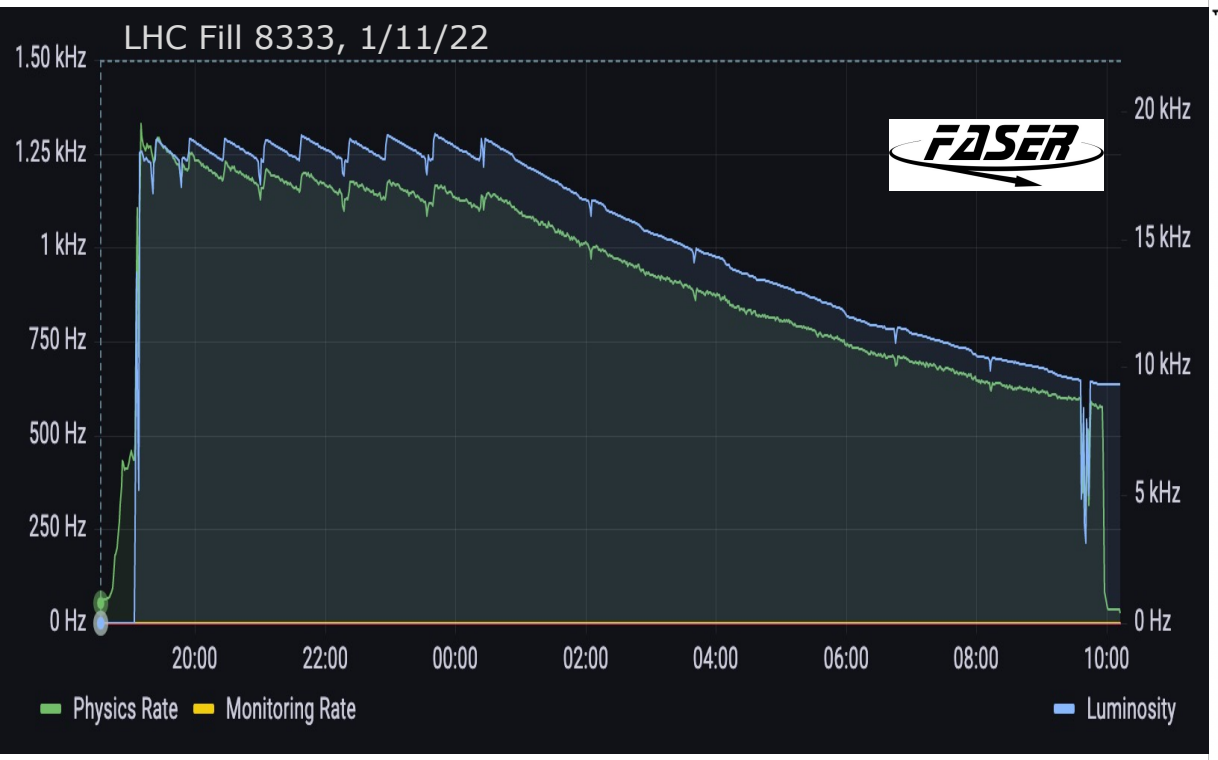
Since the muon flux is expected to vary with distance from the LOS, it is important to understand where we are measuring the flux with FASER and SND@LHC.
The ½ crossing angle of 150 µrad in 2022 running pushes the LOS at both experiments 7 cm below its nominal position.

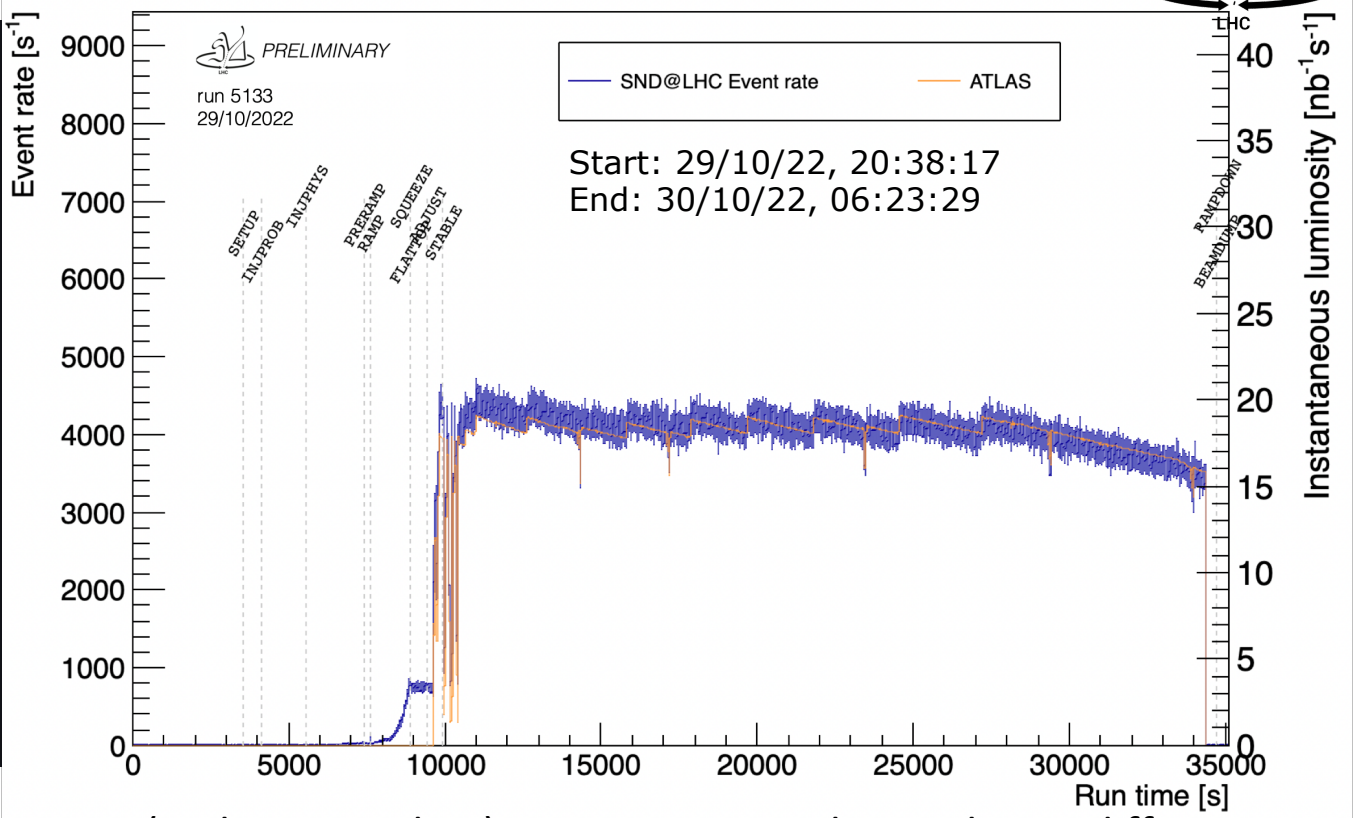
Summary:

- FASER electronic detector centre is ~6cm from LOS
- FASERnu detector centre is ~4cm from LOS
- SND@LHC emulsion target and electronic detector centre is ~44cm from LOS



Electronic Detector Trigger Rates



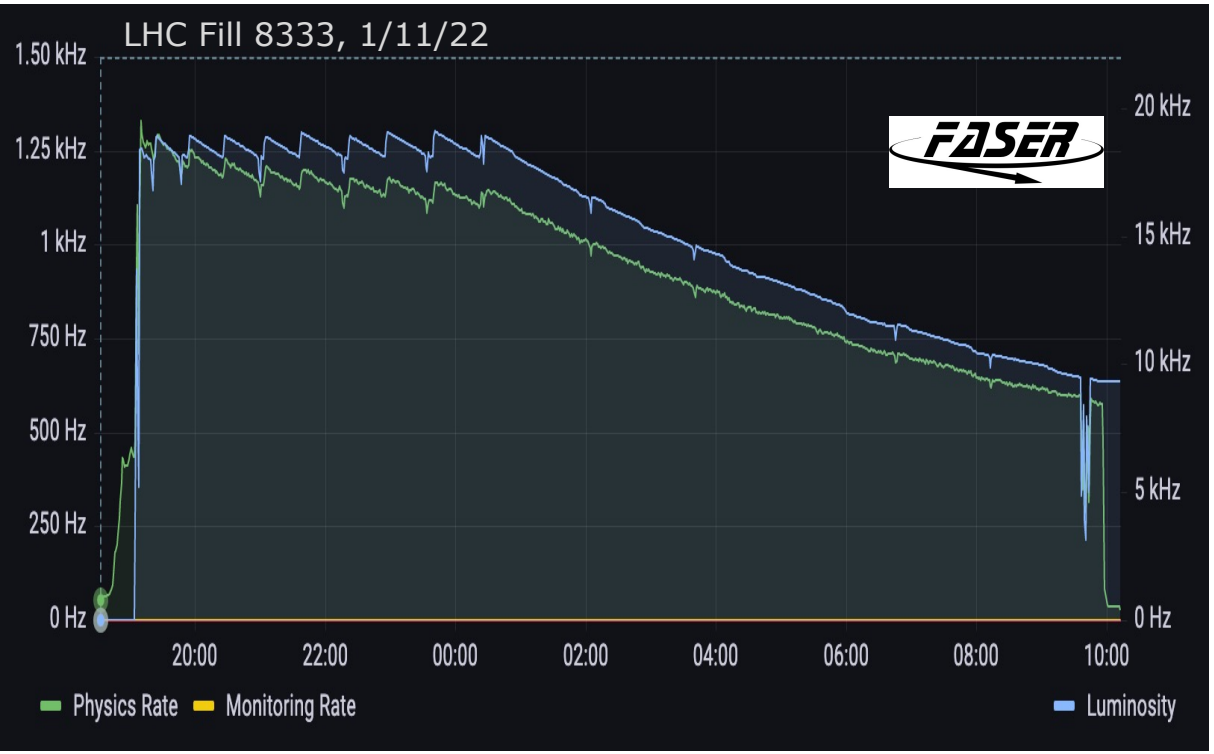


Trigger rate at max. luminosity different between the 2 experiments (1.2kHz vs 4.2kHz) - not unexpected considering different detector size and location.

FASER and SND@LHC see similar trends in their trigger rate:

- Dominatantly correlated with luminosity
- Rate non-zero and grows during the beam RAMP (before beams are colliding)
- During first few hours rate falls off faster than luminosity (likley a beam background component related to beam losses early in the fill)
    - Beam background component probably not relevant for FPF since FPF is well shielded from LHC beamline (by >10m of rock)

Electronic Detector Trigger Rates



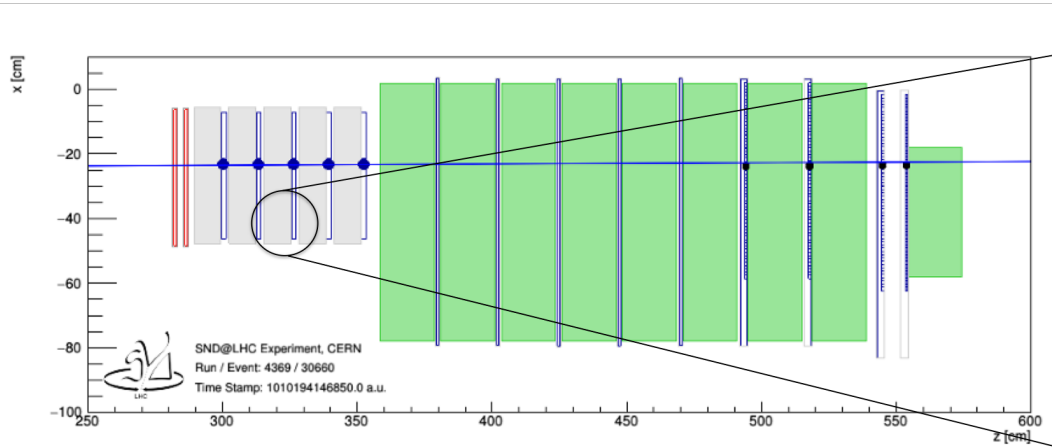
FASER trigger rate at 2e34cm^{-2}s^{-1} is ~1.3 kHz – significantly higher than the FLUKA expectation of 750Hz.
Looking at the individual scintillator rates shows that the rate of 'high energy' through going muons is consistent with the FLUKA estimate at the 20-25% level (FLUKA estimate has a ~50% uncertainty).
Extra rate comes from:

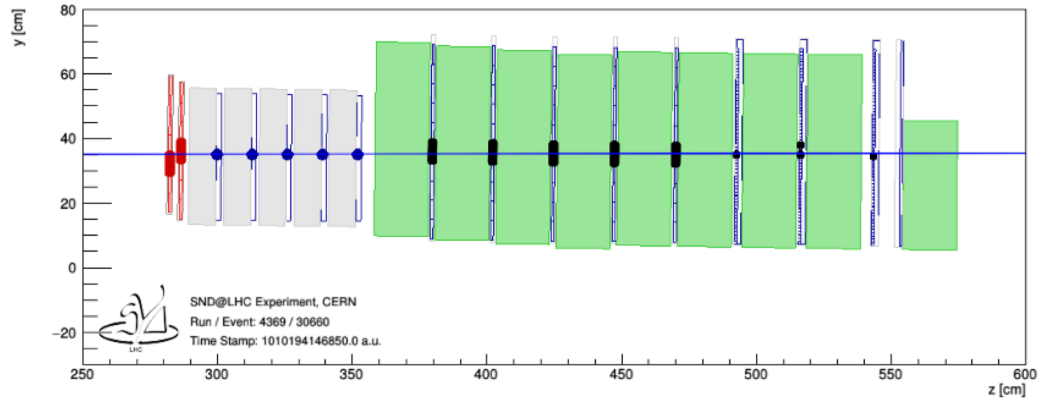
- Low energy particles firing single scintillators (not in time with colliding bunches, but only there with beams colliding)
- Beam-1 background (i.e. trigger rate correlated with incoming beam bunch passing the back of FASER (beam-1))

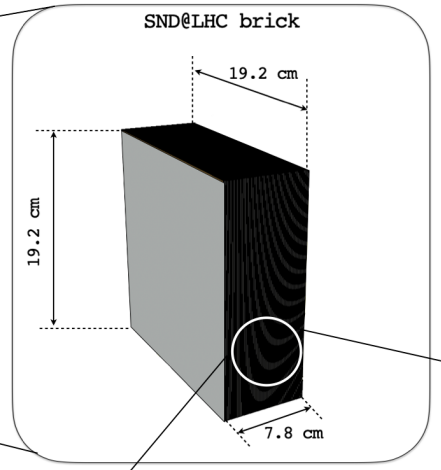
These likely not to be relevant for FPF due to shielding.

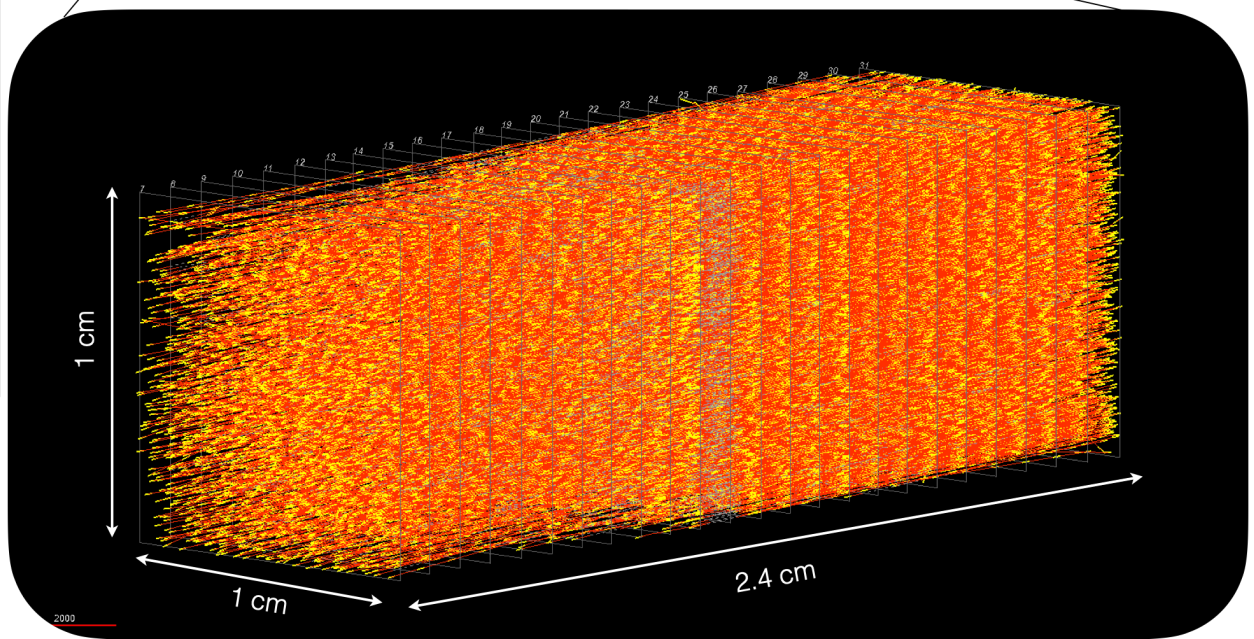
SND@LHC MEASUREMENTS

RUN0 emulsion target: April 7th - July 26th (0.51 fb^{-1})









Electronic detector reconstruction:
muon track from pp collisions @13.6 TeV
(July 6th 2022)

Observed Rates:

Measured track rate in SciFi tracker (39x39cm^2 area): 1.9x10^4 trks/cm^2/fb^{-1}

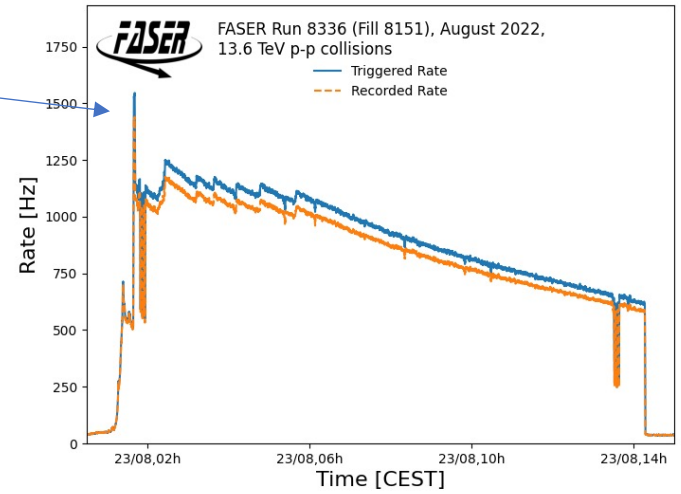
Compatible rate observed in RUN0 emulsion (19x19cm^2) (0.5/fb exposure)

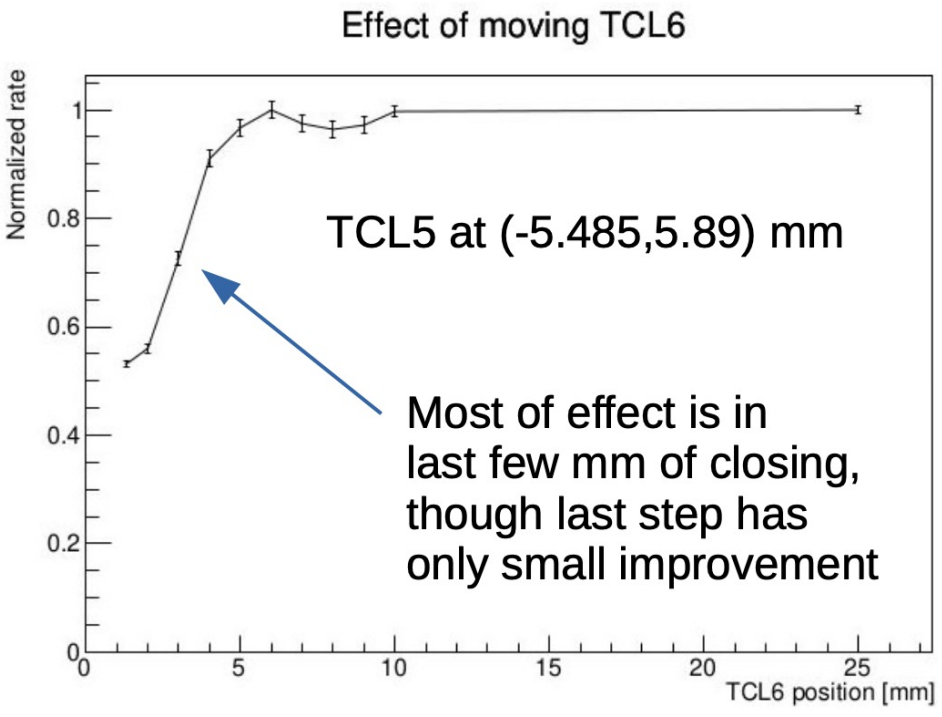
FLUKA estimate ~x2 larger

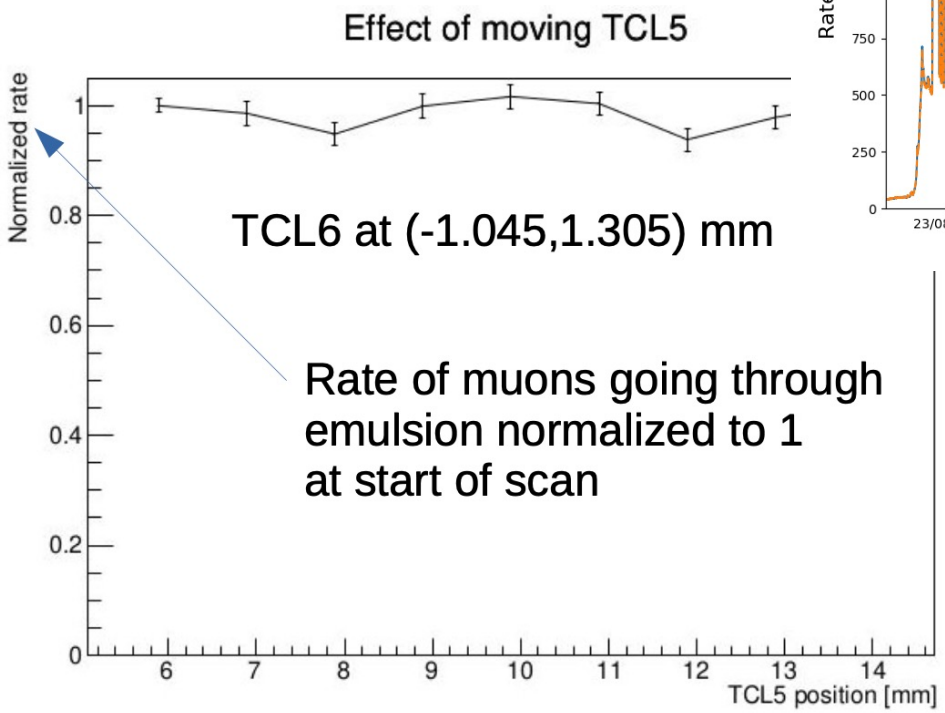
Collimator dependence at FASER

At start of Run 3 noticed FASER trigger rate was significantly higher for first ~10mins of fill. Rate drop correlated with movement of the TCL collimators (which are changed when the AFP Roman Pot detectors are inserted a few minutes into the fill). In order to understand this we did a dedicated scan of the TCL5 and TCL6 collimator settings to see how they effect the FASER trigger rate.

Before collimator movement



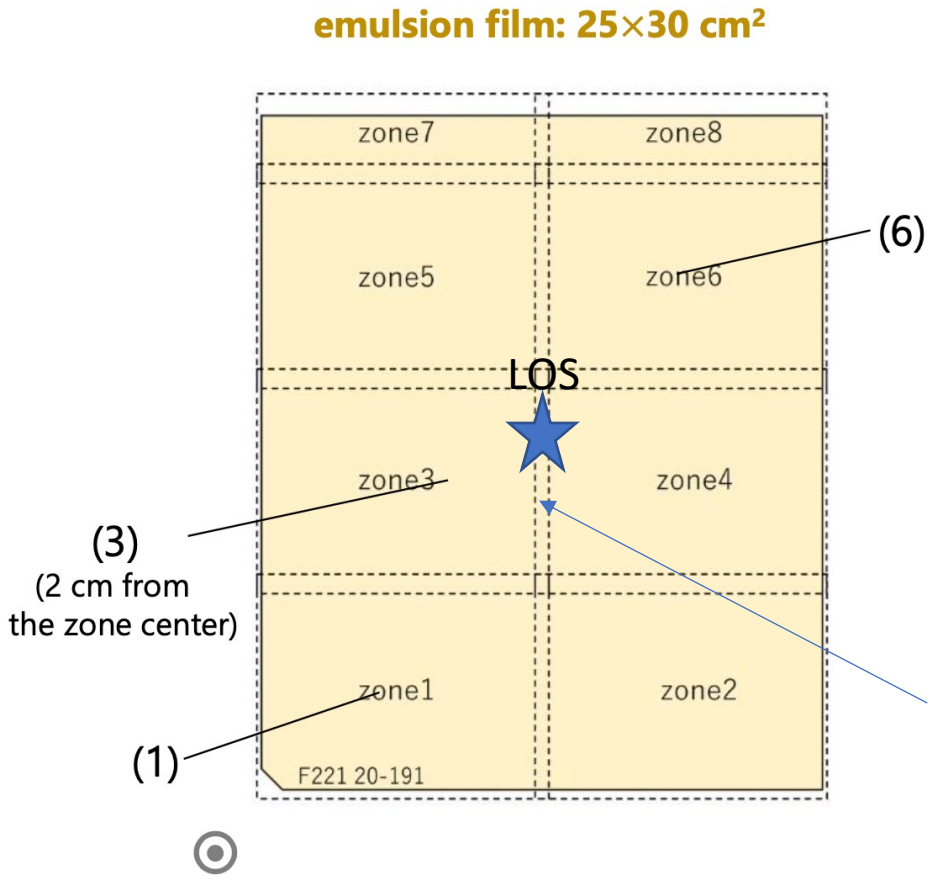




SND@LHC did not see this, which suggests the effect is very local to the LOS.
Strong dependence on TCL6 settings. FLUKA simulations for FPF used HL-LHC baseline TCL6 settings (tight).

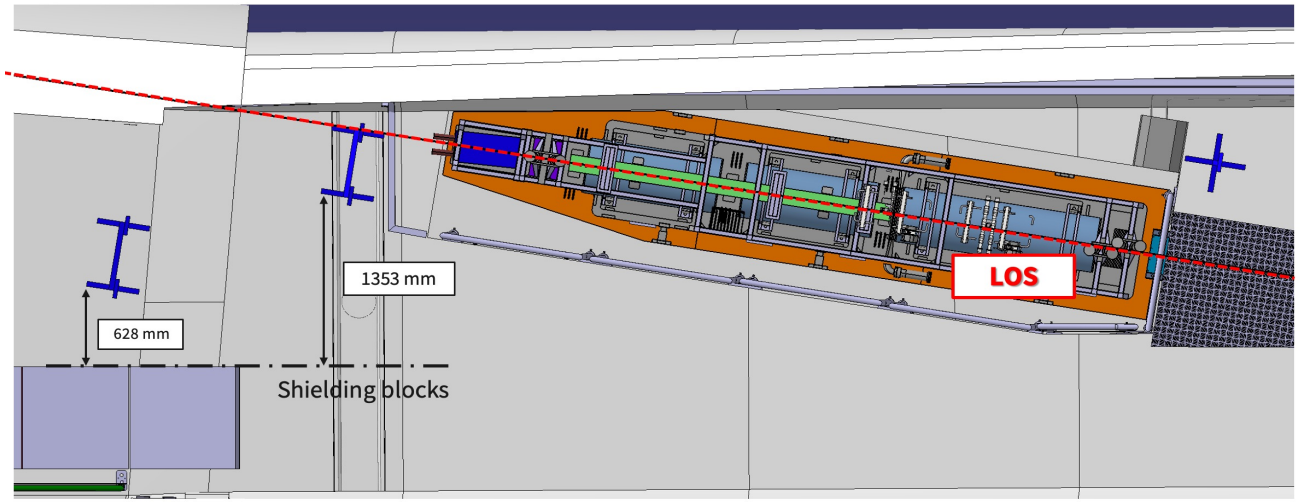
FASERν

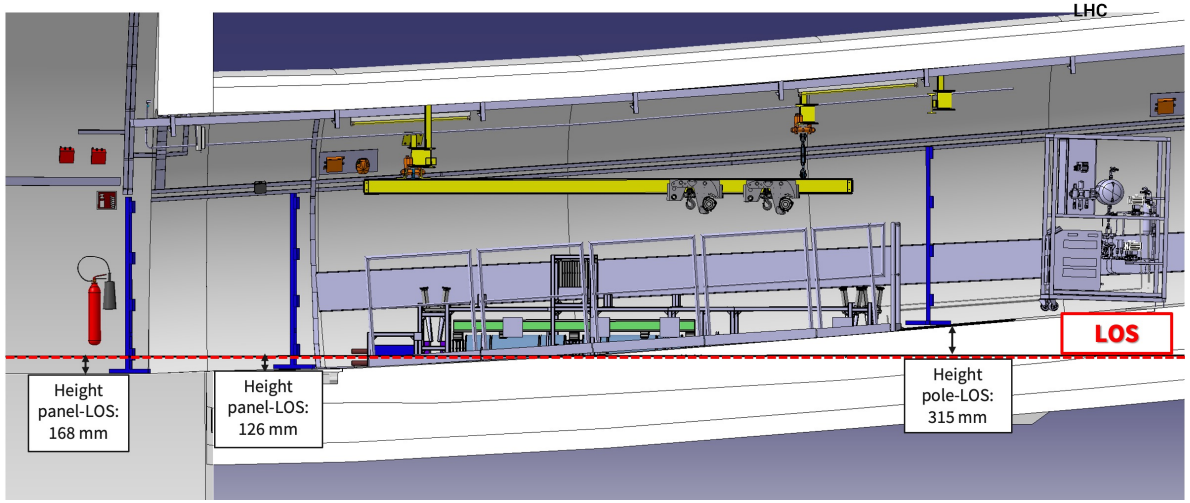
Track density in the 2022 first module



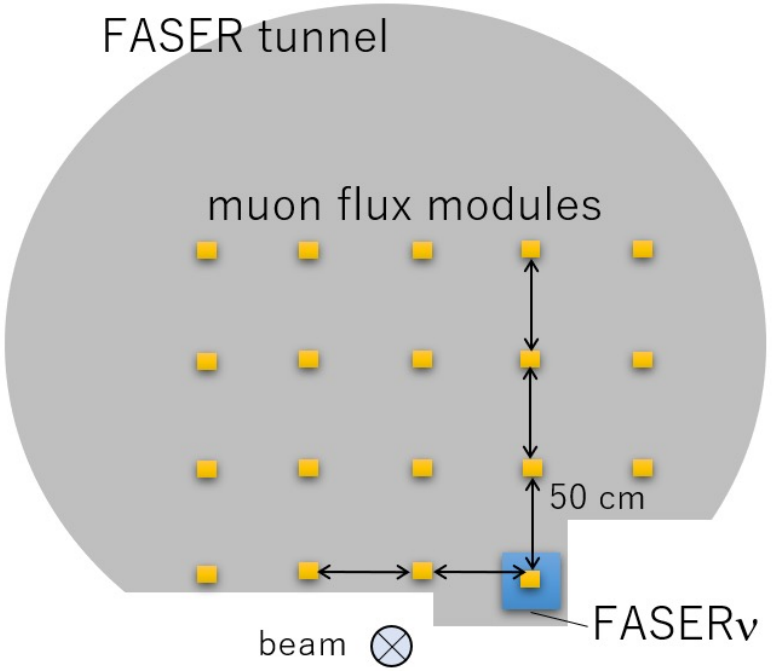
area	track density (/cm²/fb⁻¹) (all in tanθ<1.5)	track density (/cm²/fb⁻¹) (within 10 mrad from the peak)
(1)	2.3×10^4	1.3×10^4
(3)	2.2×10^4	1.2×10^4
(6)	2.0×10^4	1.1×10^4

FASER Muon fluence measurements

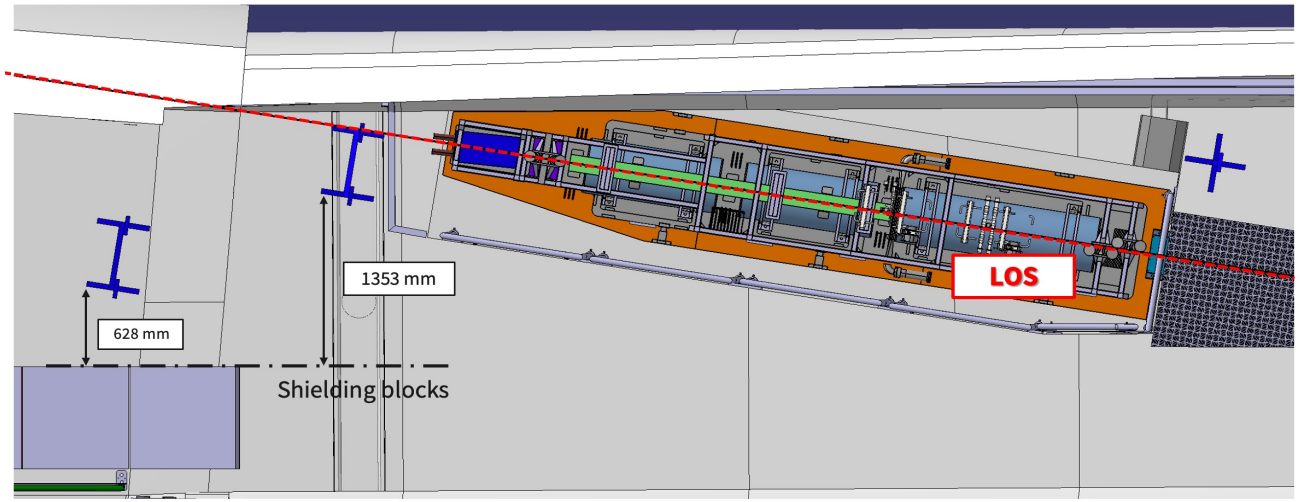


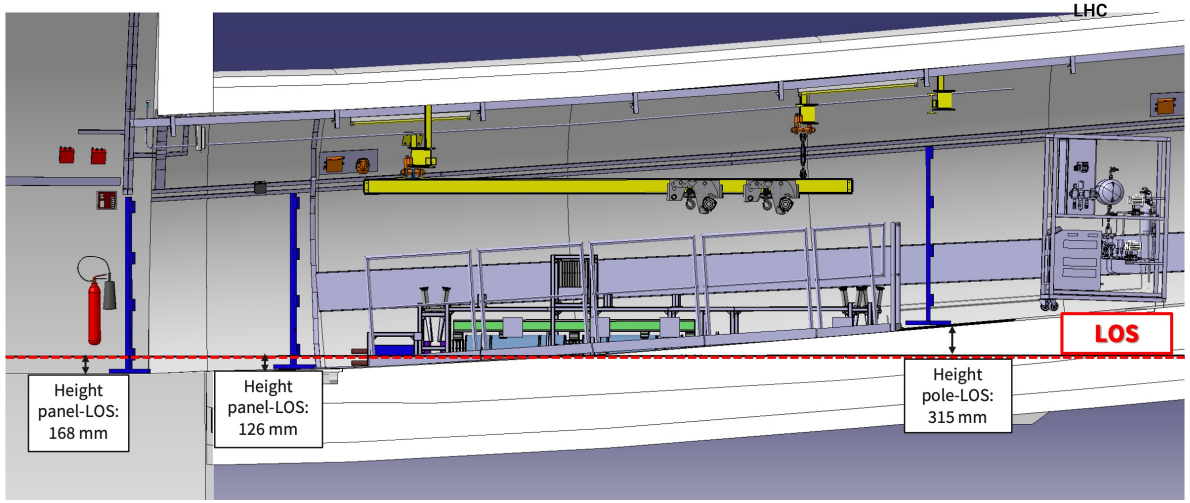


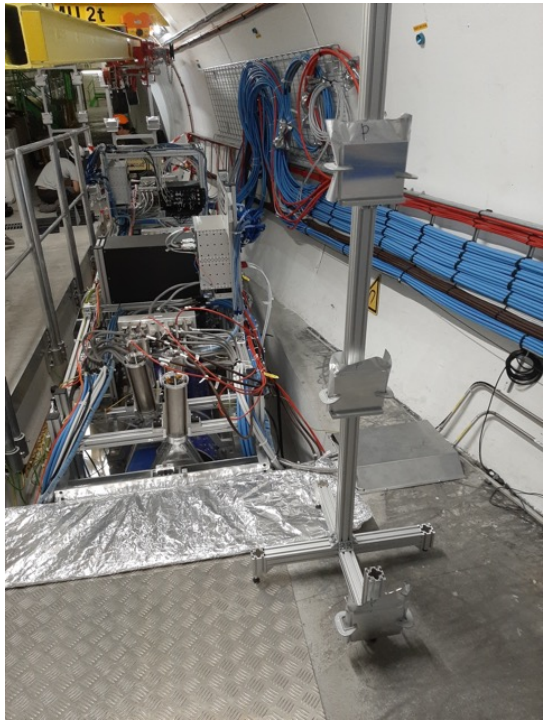
19 small emulsion detectors installed around FASER to measure the muon flux further from the LOS.
Installed in LHC tunnel 26/7 - 14/8, exposure to 10/fb of collision data.
The emulsion films have been developed and are undergoing scanning/analysis. First (very preliminary) results on next slide.

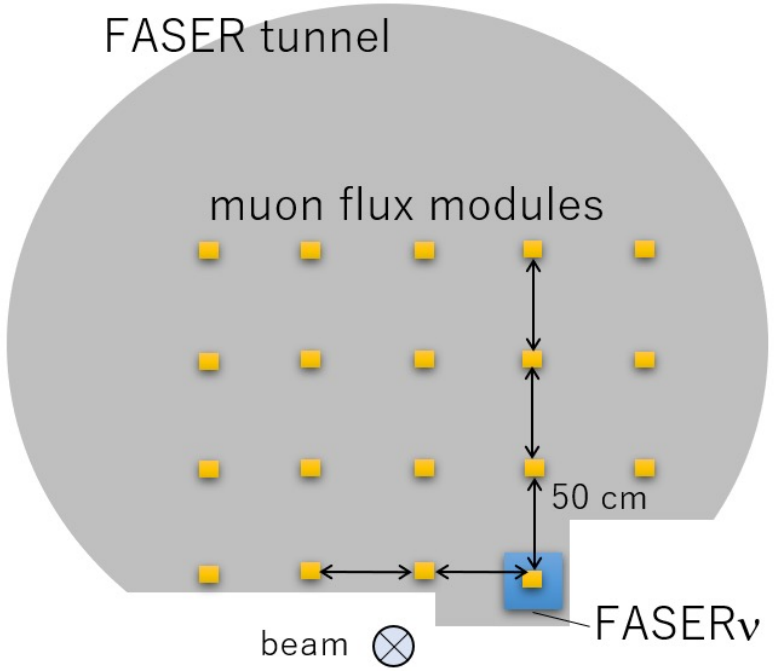


FASER Muon fluence measurements





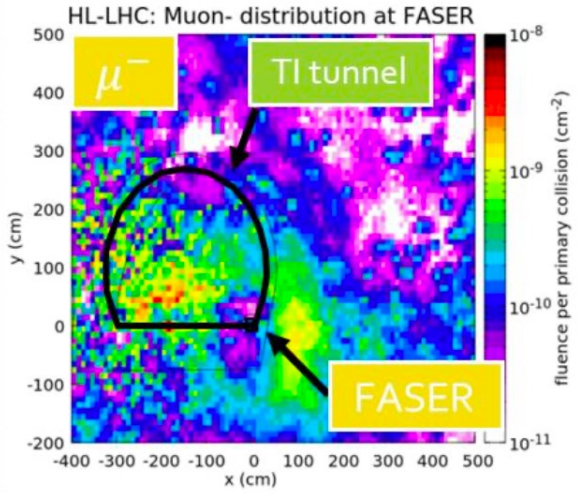


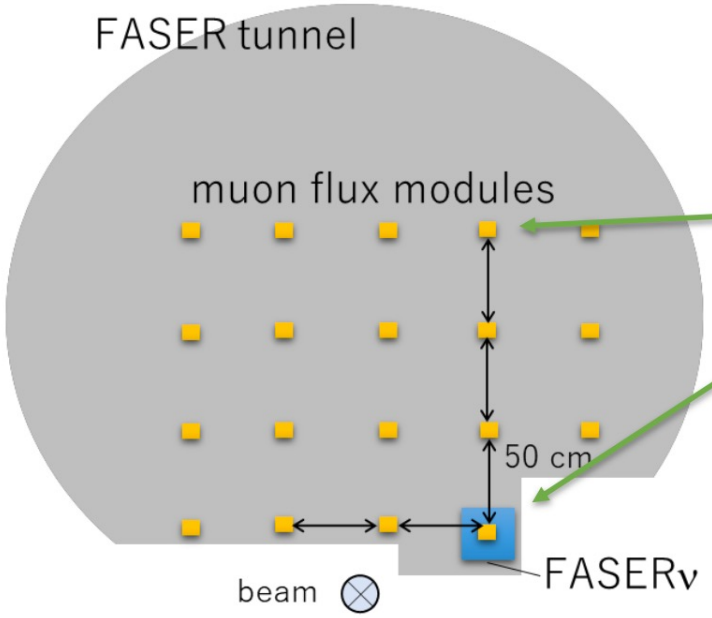


FASER Muon fluence measurements

First results from the muon modules

FLUKA simulation by CERN STI group





FASERν preliminary
(before efficiency correction)

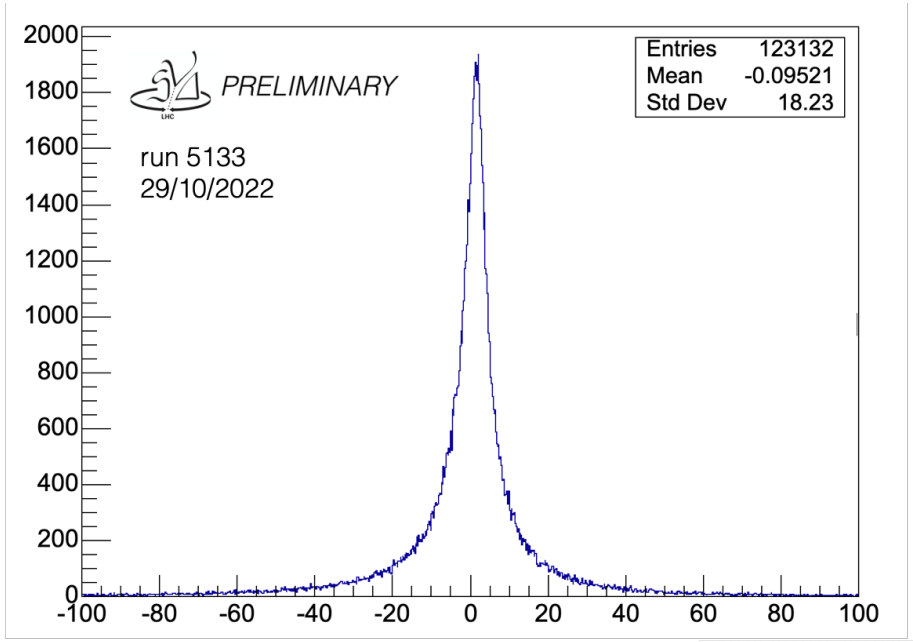
	track density (/cm^2/fb^{-1}) (within 10 mrad from the peak)
height 150 cm	3.6×10^4
height 0 cm	0.9×10^4
FASERν 1st module	1.2×10^4

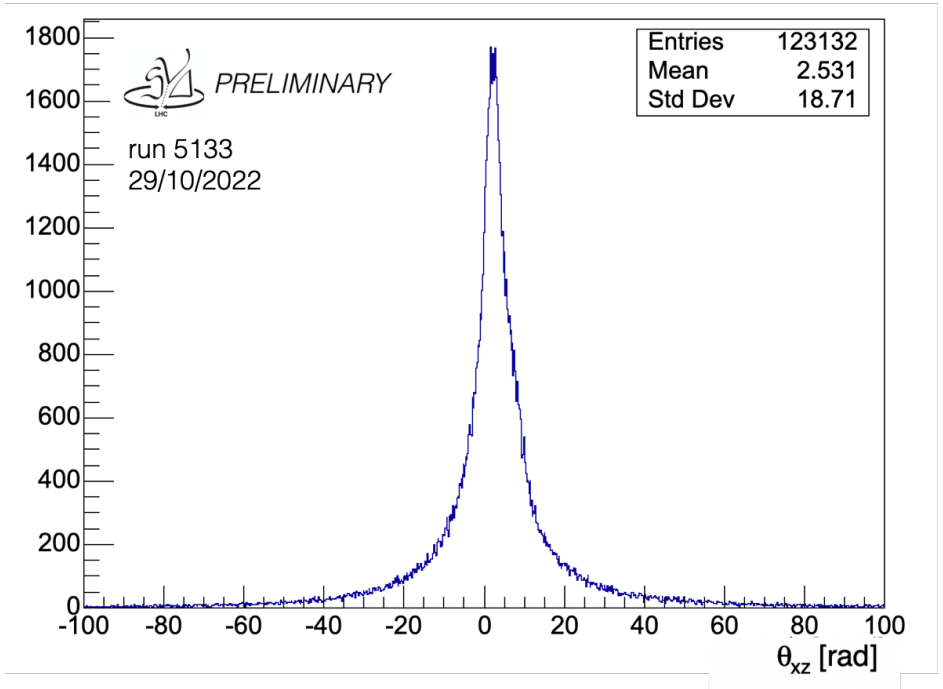
Measured flux significantly larger ~1.5m from the LOS.
More detailed analysis and measurements at other locations ongoing.

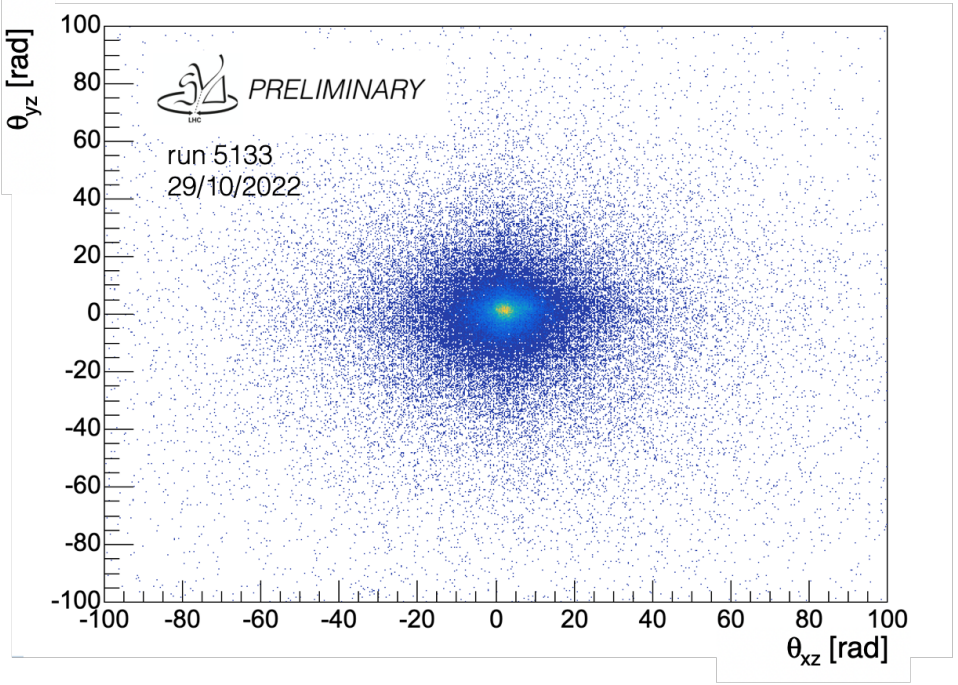
DATA TAKING IN RUN3

Reconstructed tracks by electronic detectors in pp collision runs @13.6 TeV

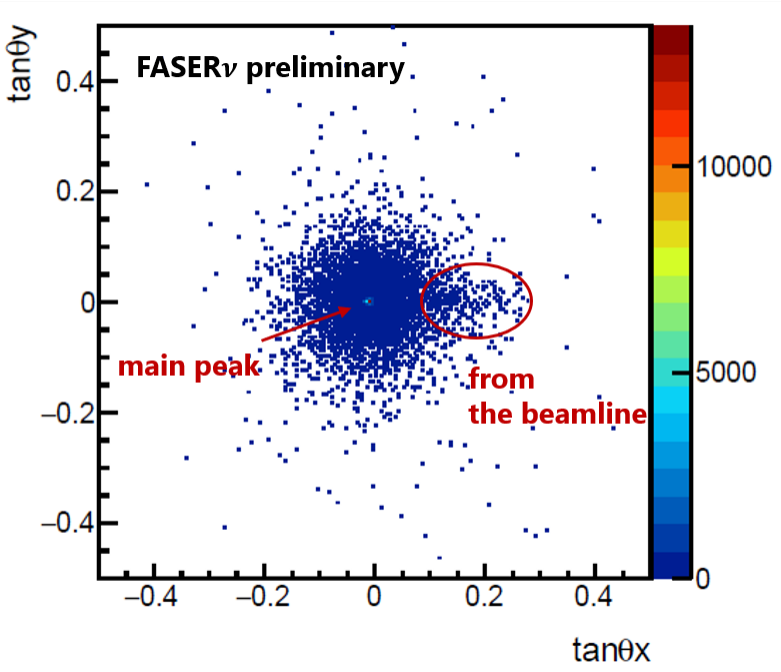
Direction compatible with coming from pp collisions at IP1

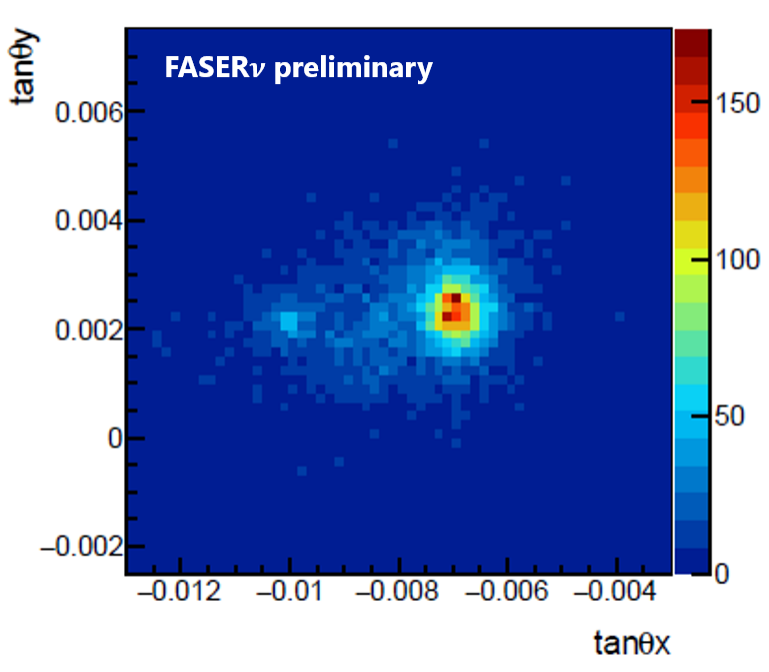


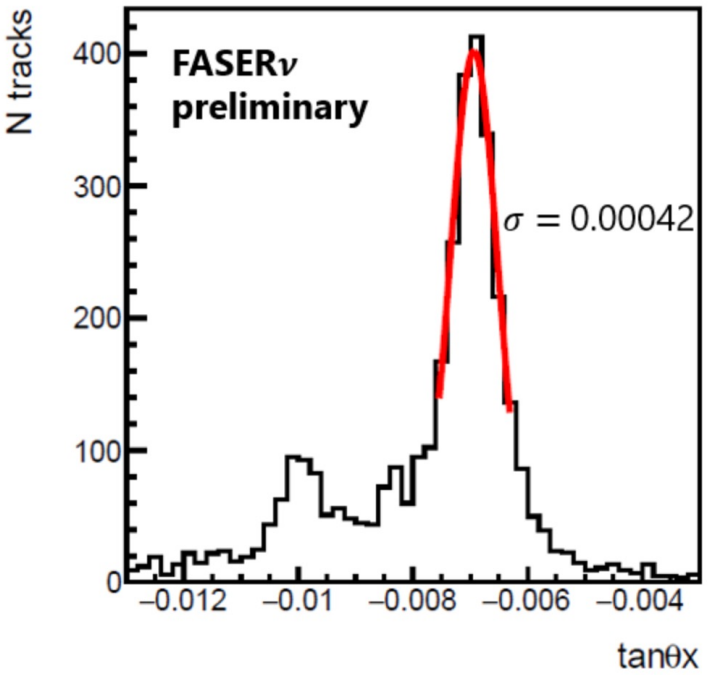


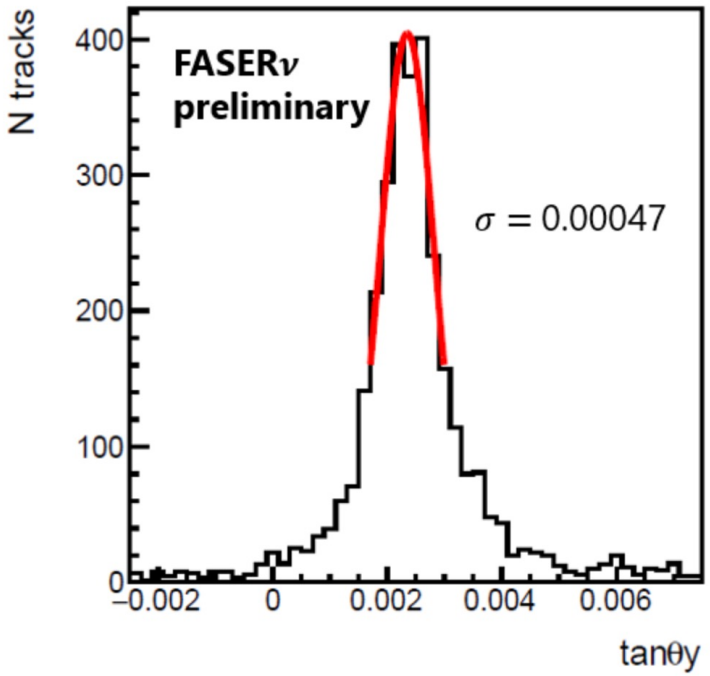


FASERν Results









Angular distributions observed using 20 emulsion films in the 2022 first module of the FASERnu detector. The angular coordinates (0, 0) roughly corresponds to the LOS (The detector inclination is not corrected).
There are two peaks separated by 0.003 rad. Both peaks are consistent with particles arriving from the beam line in the vertical plane. The origin of the two-peak structure is under investigation with simulation studies.

Sigma_x ~ 0.00042 rad
Sigma_y ~ 0.00047 rad

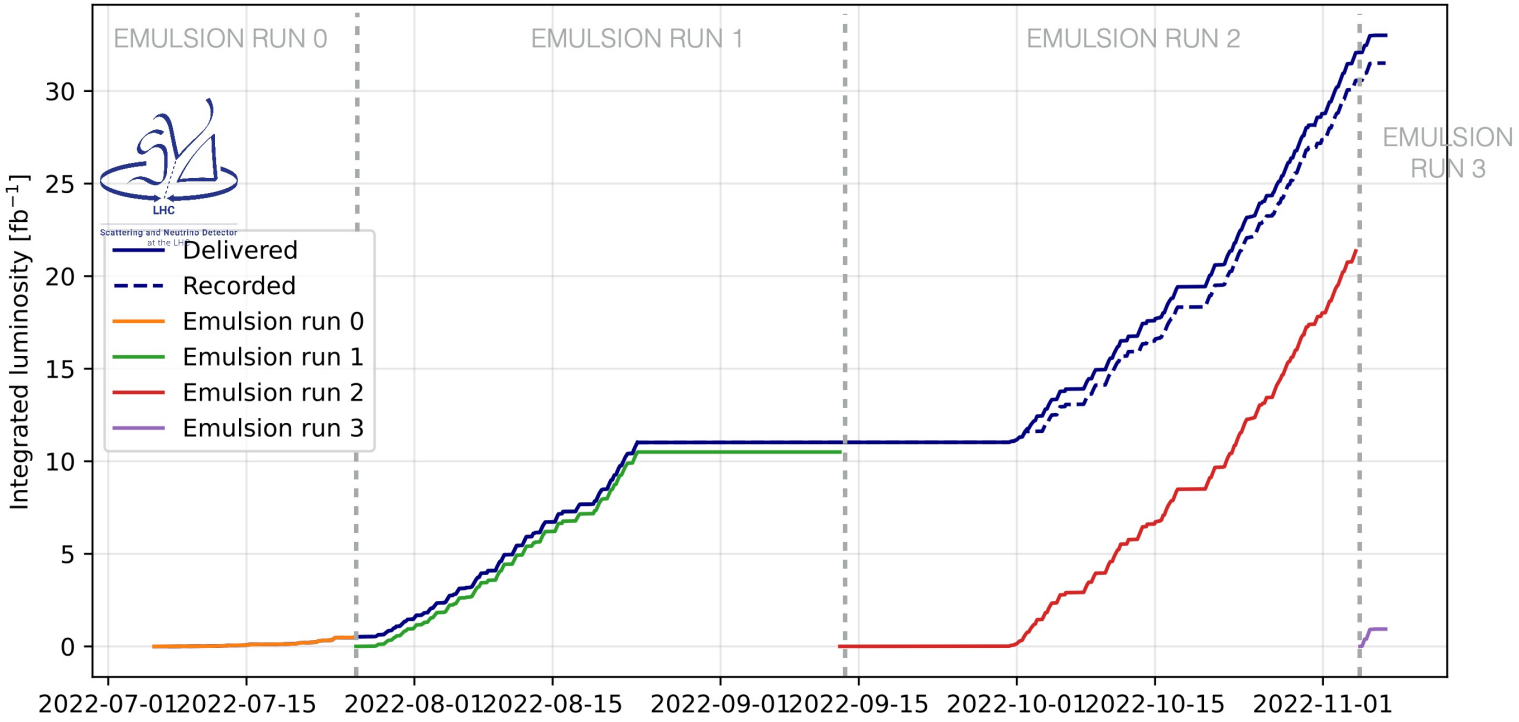
Angular spread consistent with mulitple scattering in ~100m of rock for particle of several hundred GeV. (2mrad corresponds to 270GeV).

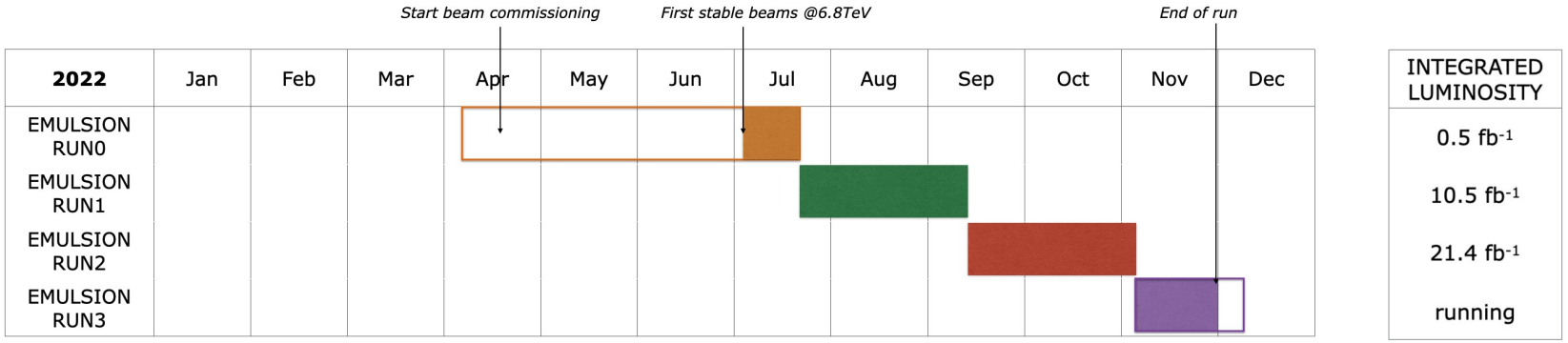
Summary

- First (very preliminary) results from FASER and SND@LHC show a track rate of ~1 – 2 x 10^4 cm^{-2}/fb^{-1} consistent at the factor of 2 level with FLUKA simulations
  - Rate on LOS very sensitive to TCL6 collimator settings (tight settings reduce rate)
- Simulations predict the rate rises away from the LOS, as indicated by the FASERν muon measurement 1.5m away from the LOS.
- Dedicated small emulsions to measure rate away from LOS will provide further information once analysed
- Significnat updates to the LHC infarstructure between IP1 and FPF, mean Run 3 measurements not directlty applicable to FPF, but can be used to benchmark simulations which can then be applied to the HL-LHC scenario

BACKUP….

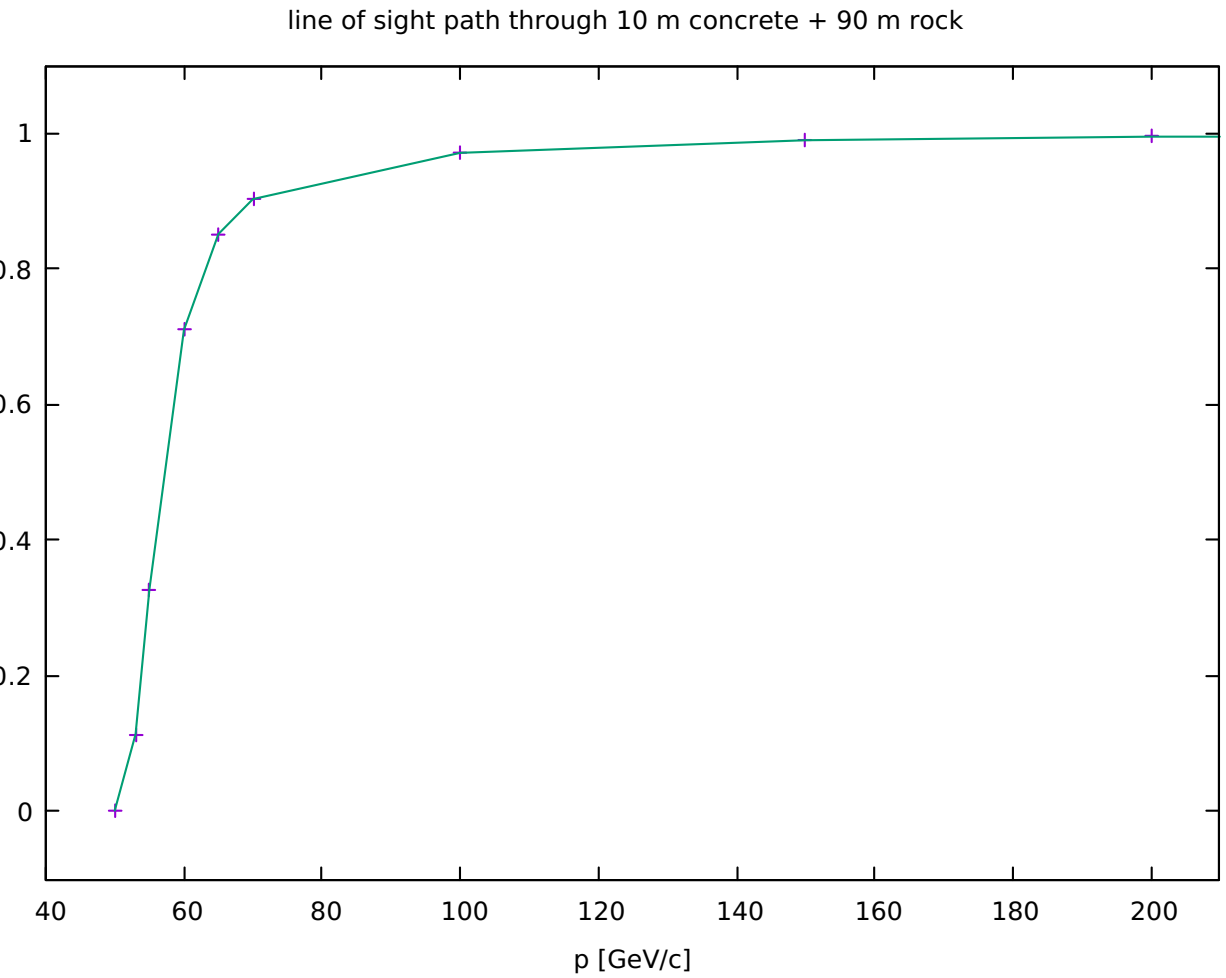
DATA TAKING IN RUN3

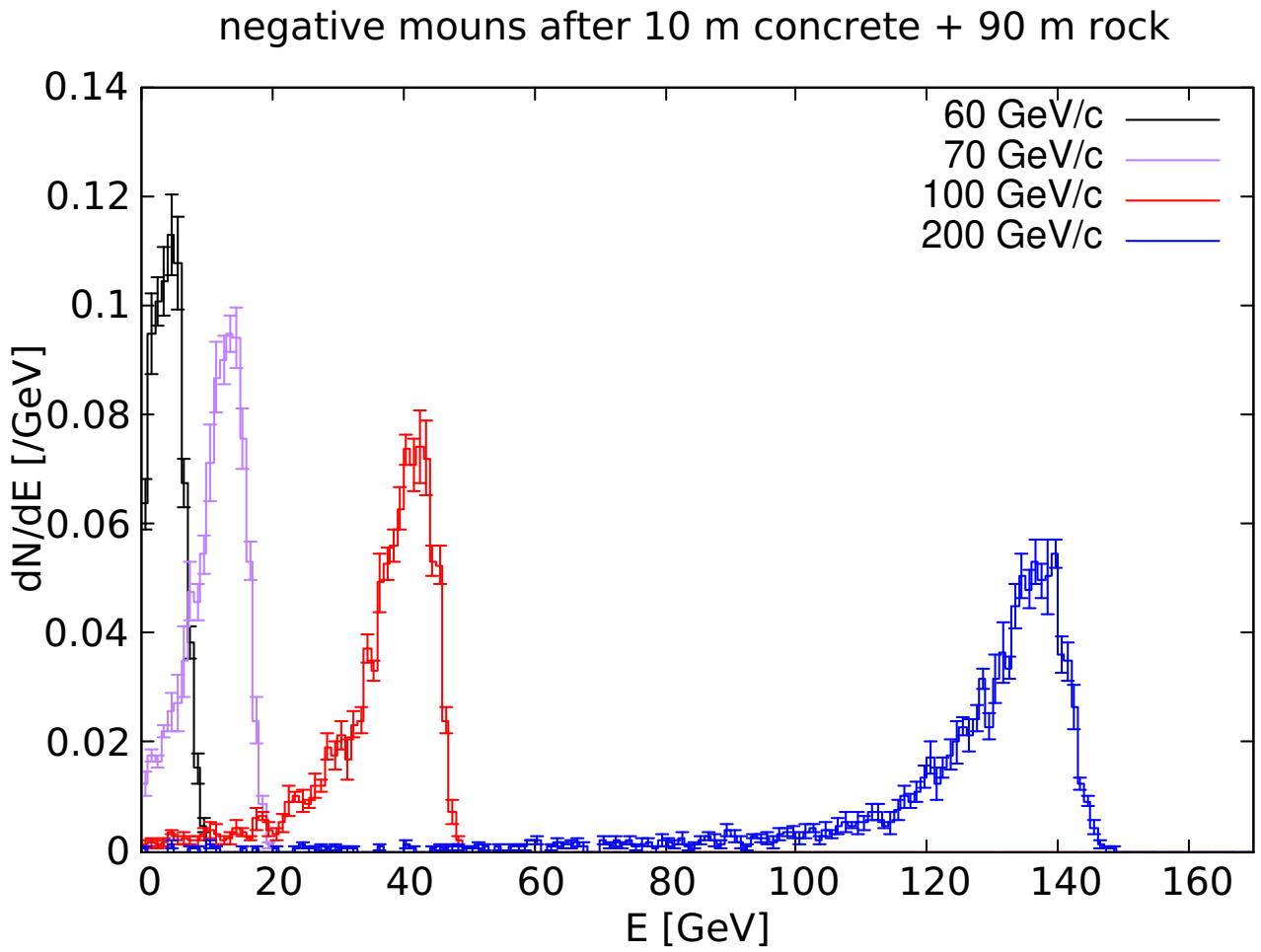




INTEGRATED LUMINOSITY
0.5 fb^{-1}
10.5 fb^{-1}
21.4 fb^{-1}
running

Muon energy loss in rock





FLUKA simulation of muons going to FASER/SND@LHC (through 90m rock + 10m concrete) – average energy loss 60 GeV.
For FPF energy loss will be double this – 120 GeV.