presentation of XSEN

(**X**-**S**ection of **E**nergetic **N**eutrinos)

neutrino fluxes from pp collisions at LHC and XSEN location

October 17, 2019 SHiP JPD meeting Marco Dallavalle (INFN Bologna)

XSEN project

It acquired weight during Run2,
when the LHC luminosity touched 2×10^{34} /cm^2/sec at IP1 and IP5

— how big is the flux of neutrinos from the Interaction Point ?
— can we observe them? how? where? backgrounds?

- https://edms.cern.ch/ui/file/1908776/1.0/LHC-XSEN-EC-0001-1-0.pdf March 19, 2018.
- http://arxiv.org/abs/1804.04413 CMS-Note 2018/001 April 12, 2018
- https://edms.cern.ch/ui/file/2022399/1.0/LHC-XSEN-EC-0002-1-0.pdf September 5, 2018
- https://dx.doi.org/10.1088/1361-6471/ab3f7c "Physics Potential of an Experiment using LHC Neutrinos" (March 5, 2019) N. Beni et al, J. Phys. G: Nucl. Part. Phys. 46 (2019) 115008

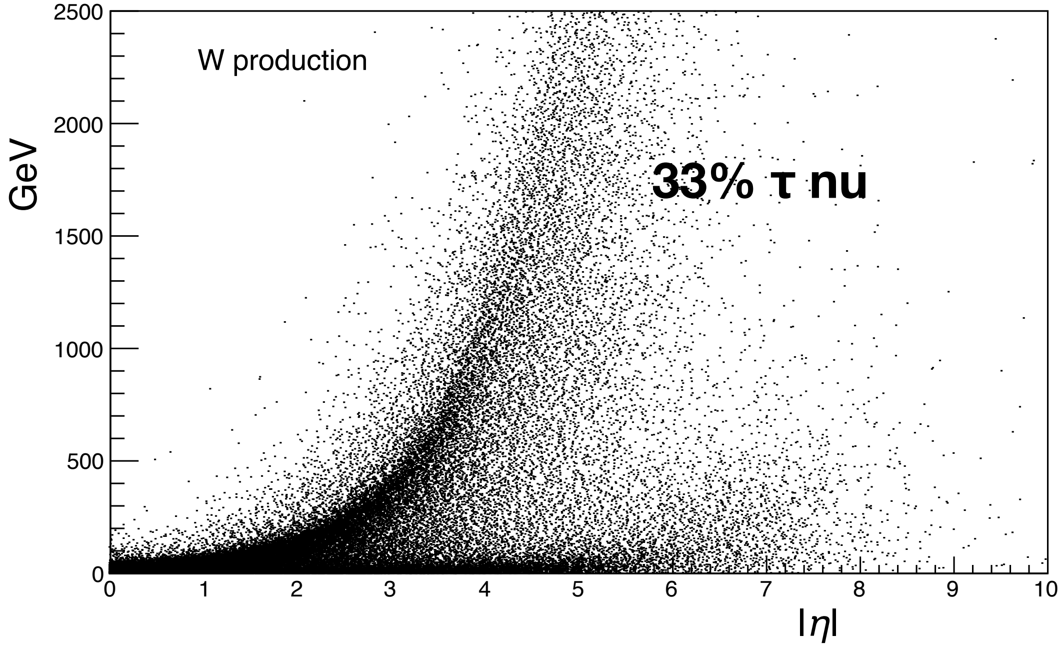
https://cds.cern.ch/record/2691399 Letter of Intent , XSEN: a νN Cross Section Measurement using High Energy Neutrinos from pp collisions at the LHC, Sep.9, 2019, CERN-LHCC-2019-014 ; LHCC-I-033
Beni, N ; Buontempo, S ; Camporesi, T ; Cerutti, F ; Dallavalle, G M ; De Lellis, G ; De Roeck, A ; De Rújula, A ; DiCrescenzo, A ; Fasanella, D ; Ioannisyan, A ; Lazic, D ; Margotti, A ; LoMeo, S ; Navarria, F L ; Patrizii, L ; Rovelli, T ; Sabaté-Gilarte, M ; Sanchez Galan, F ; Santos Diaz, P ; Sirri, G ; Szillasi, Z ; Wulz, C

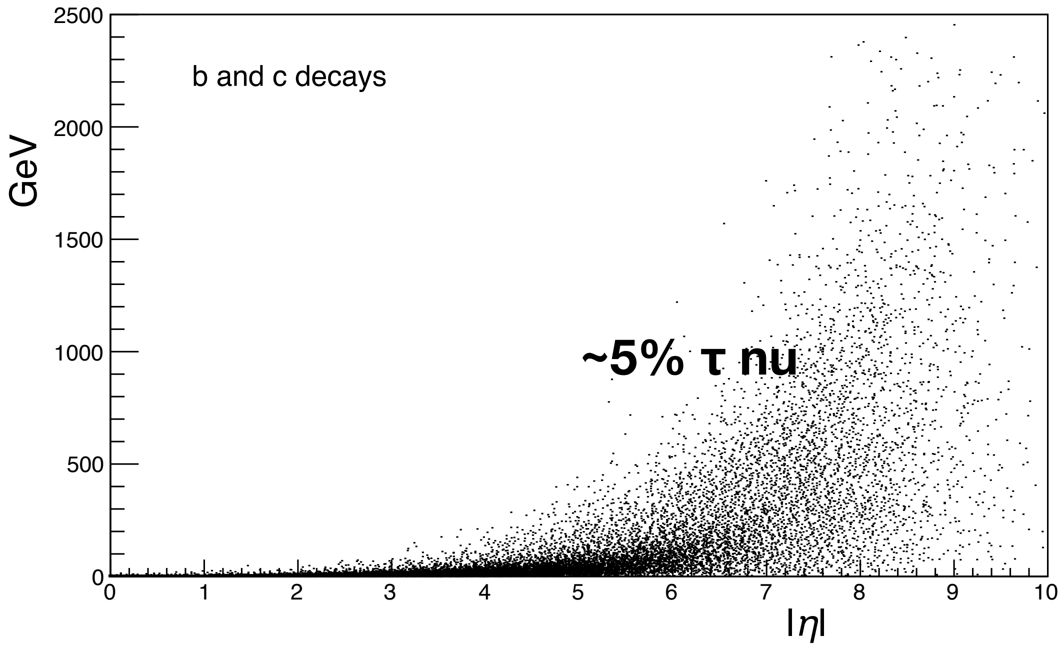
The Physics idea is 30-years old:

A. De Rùjula (CERN), Neutrino Physics At Future Colliders (1984).
Published in **IN *PRAGUE 1984, PROCEEDINGS, TRENDS IN PHYSICS, VOL. 1* 236-245.**

A. De Rùjula, R. Ruckl (CERN), Neutrino and muon physics in the collider mode of future accelerators CERN-TH-3892/84 (May 1984). DOI: 10.5170/CERN-1984-010-V-2.571

A.De Rùjula, E.Fernandez, and J.J.Gòmez-Cadenas,"Neutrino fluxes at future hadron colliders", *Nucl. Phys.* **B405** (1993) 80–108.





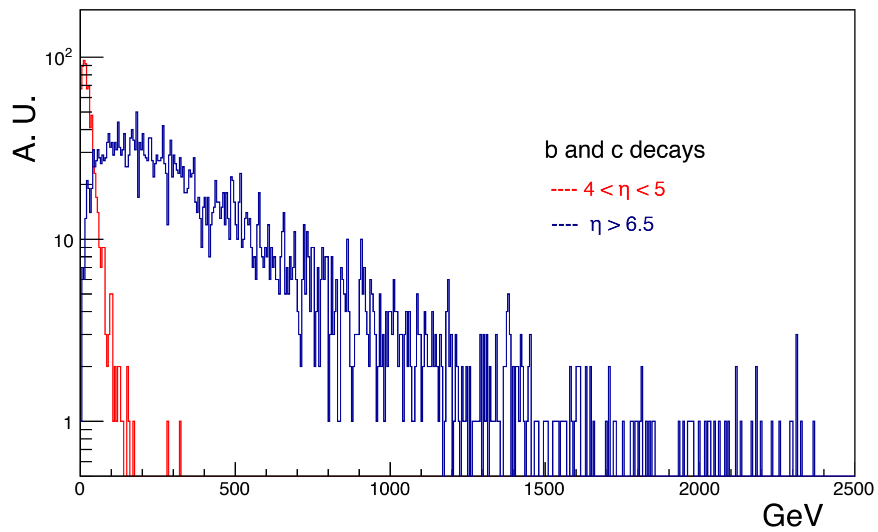
neutrino flux intensity, composition and energy depend on pseudorapity

our interest is on high energy and tau flavor

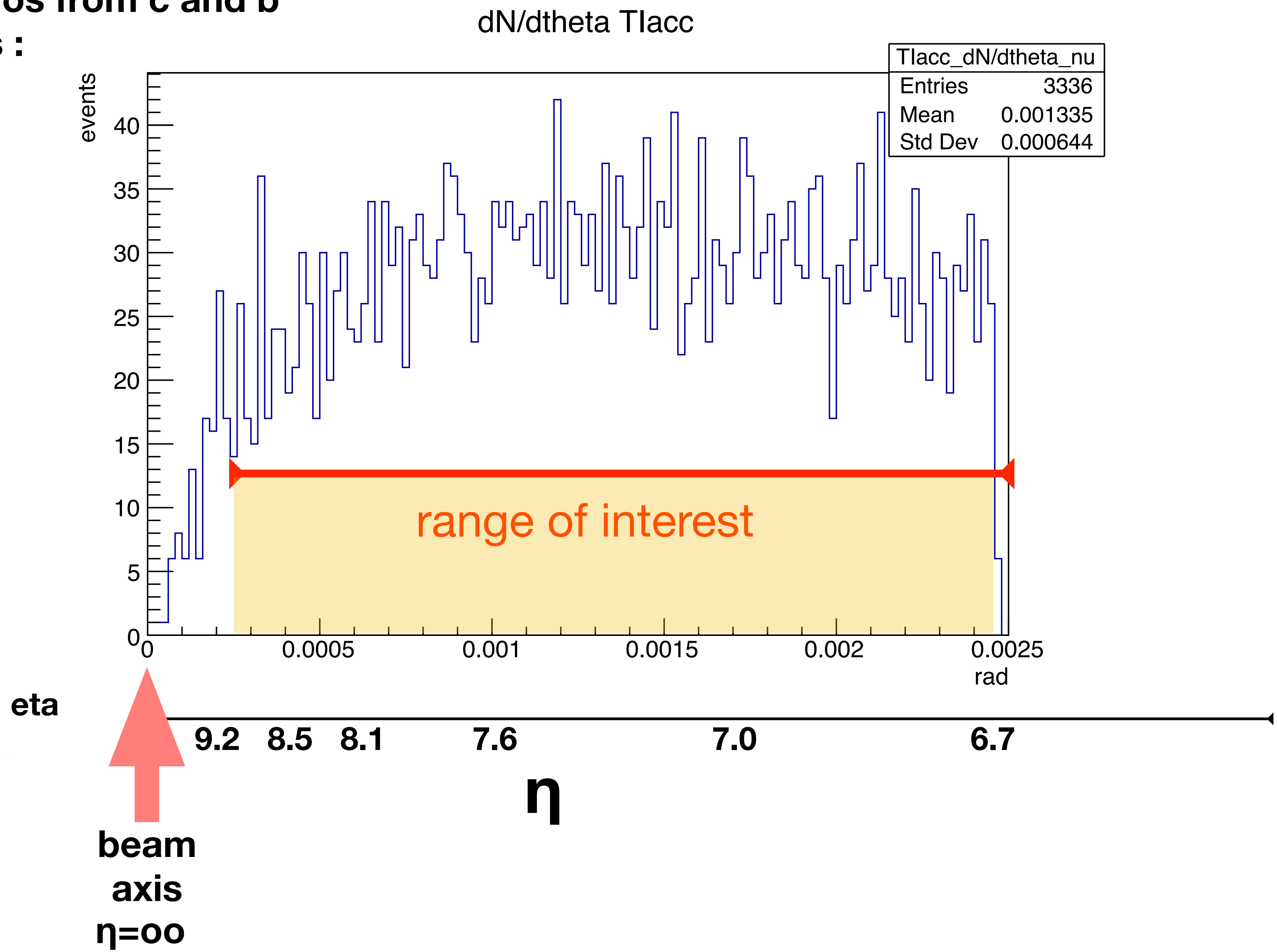
focus on two regions

- **$4<\eta<5$ leptonic W decays (33% τ nu)**
- **$6.5<\eta<9$ c and b decays (~5% τ nu)**

a detector placed some milliradians off the beam axis



theta distribution of neutrinos from c and b decays :



neutrino fluence from IP (5 or 1)

Table 1: Neutrino fluences in $4 < |\eta| < 5$, $|\eta| > 6.5$, for 3000 fb^{-1}.

	$4 < \|\eta\| < 5$	$\|\eta\| > 6.5$
Neutrinos from pp collisions at $\sqrt{s}$=14 TeV with c and b production		
neutrino fluence in acceptance /3000 fb^{-1}	$3.9\ 10^{14}$	$1.7\ 10^{14}$
τ neutrino fluence in acceptance /3000 fb^{-1}	$2.7\ 10^{13}$	$9.3\ 10^{12}$
neutrino average energy (RMS) (GeV)	30(30)	400(350)
Neutrinos from pp collisions at $\sqrt{s}$=14 TeV with W production		
neutrino fluence in acceptance /3000 fb^{-1}	$1.7\ 10^{10}$	
τ neutrino fluence in acceptance /3000 fb^{-1}	$4.7\ 10^{9}$	
neutrino average energy (RMS) (GeV)	600(600)	

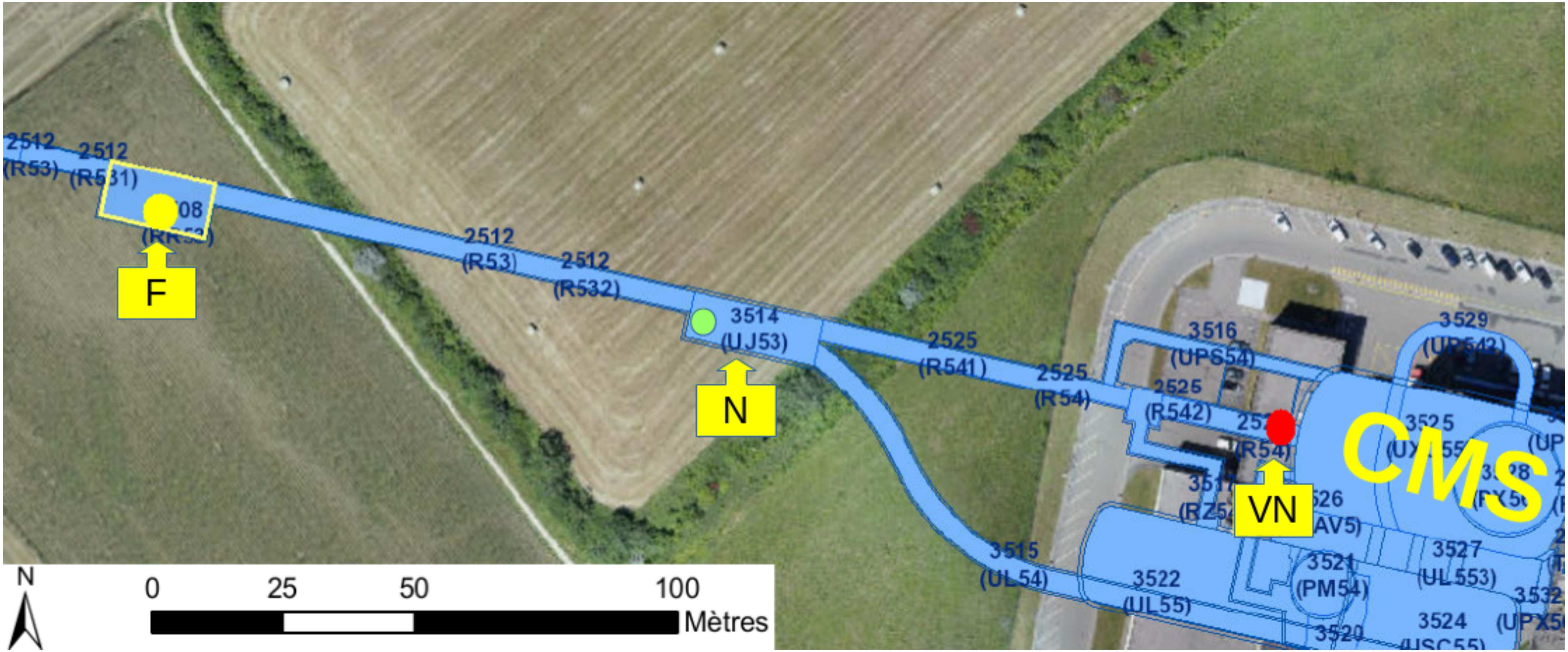
The fluence is large also when Lint =150 /fb as expected in LHC run 3

Take a first look in Run3 ? need a low background site

Winter shutdown 2017/2018, prepare for searching an appropriate site in LHC during the 2018 run

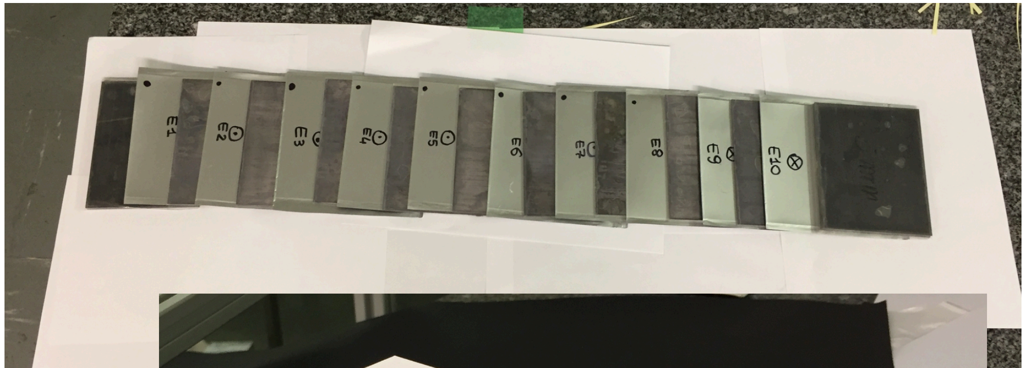
chosen sites:

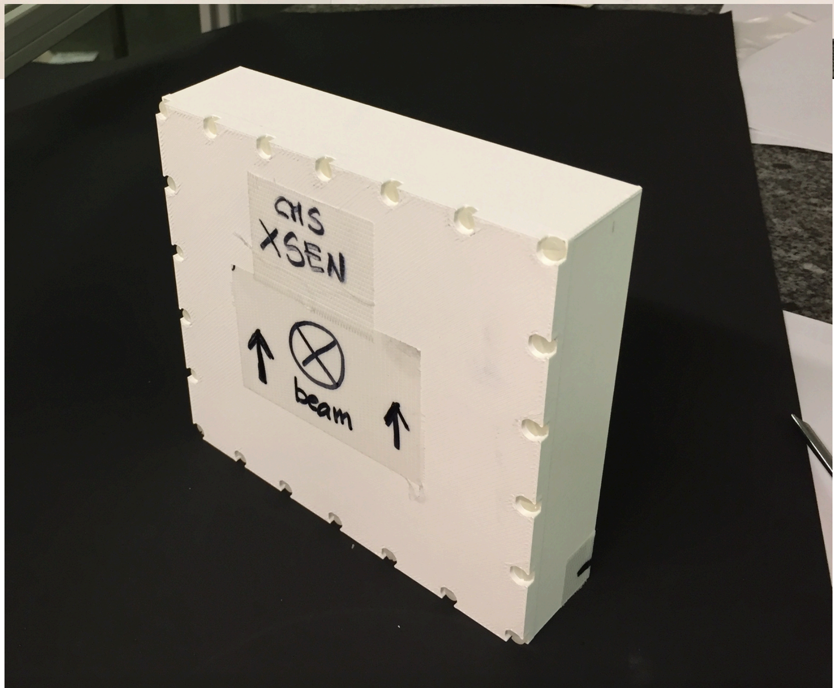
VN = Q1 of the inner triplet, 22 m from IP
N = UJ53 hall (120 m from IP) (or UJ57 @90 m)
F = RR53 hall (237 m from IP) (or RR57)

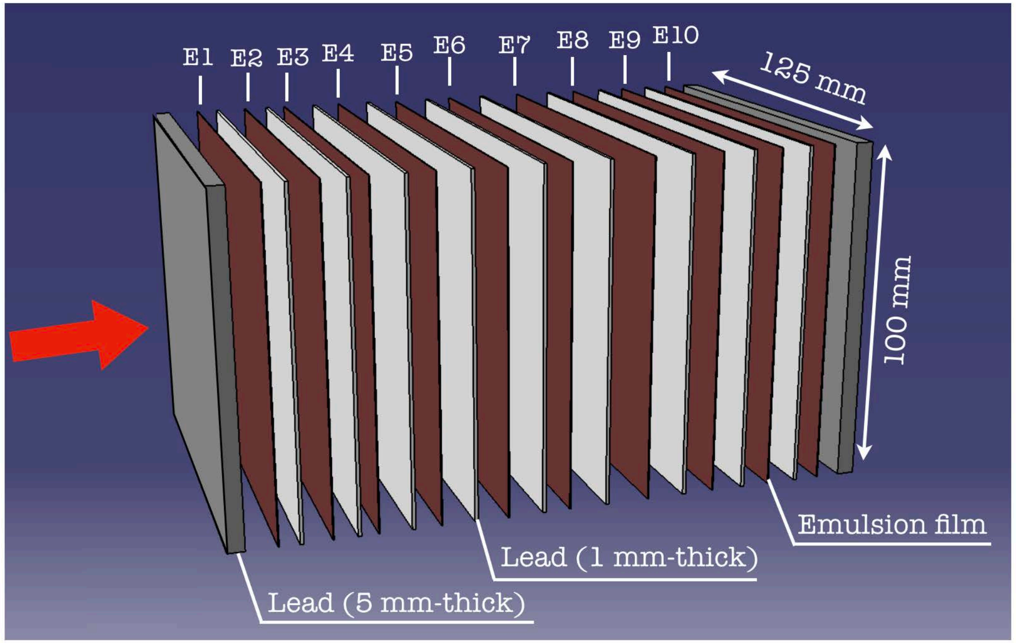


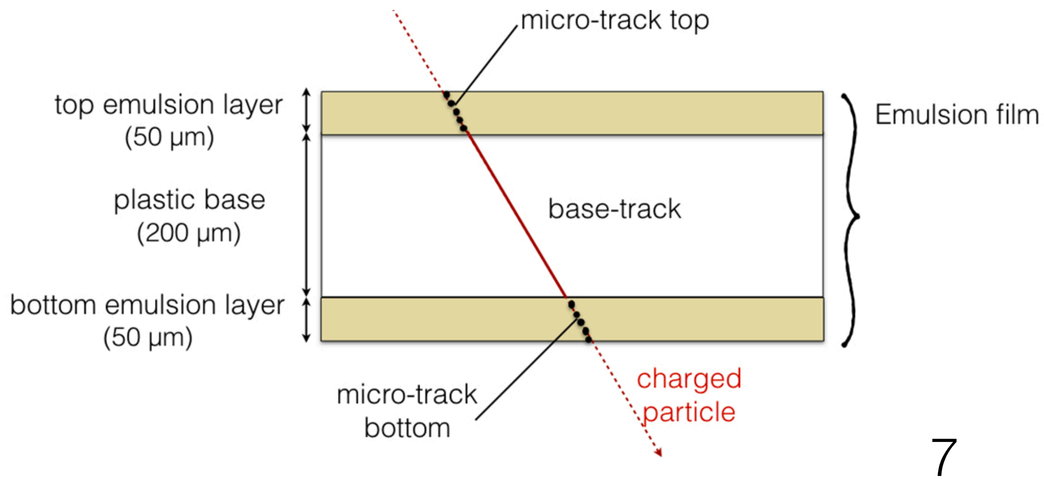
TREX and LMC gave green light with a limitation: the test detector should not interfere with LHC

use nuclear emulsions in the modular design developed by OPERA: emulsions interleaved with thin layers of lead packed together into “bricks”.





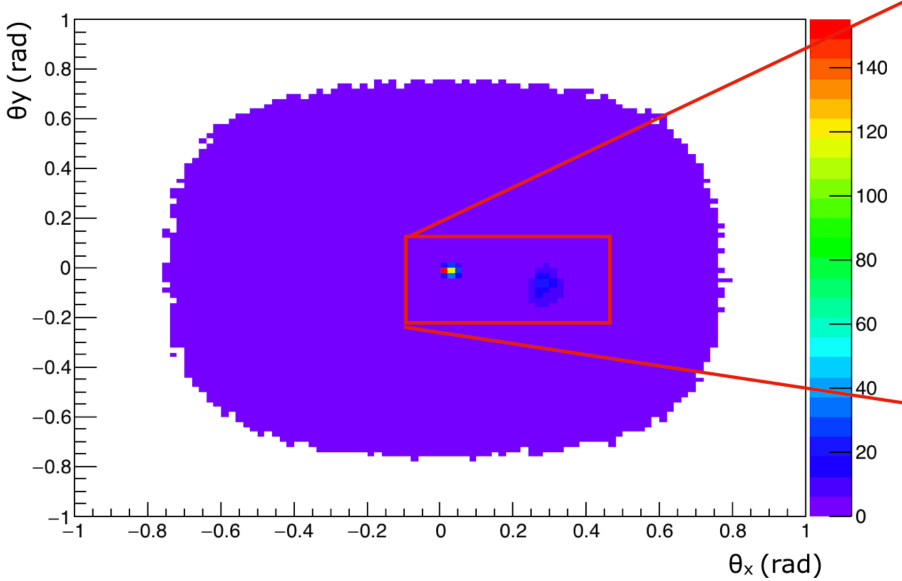


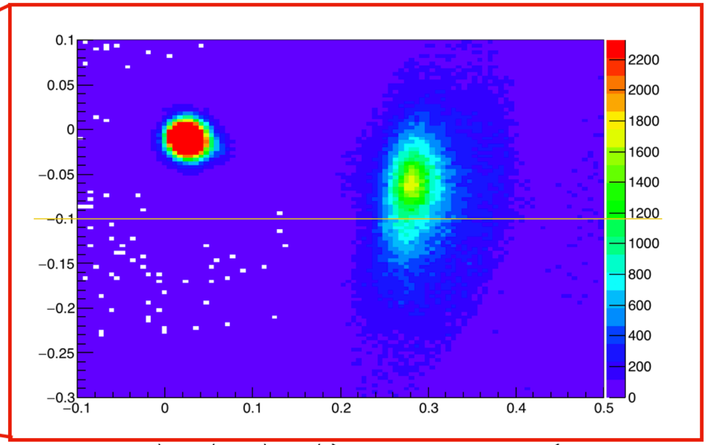


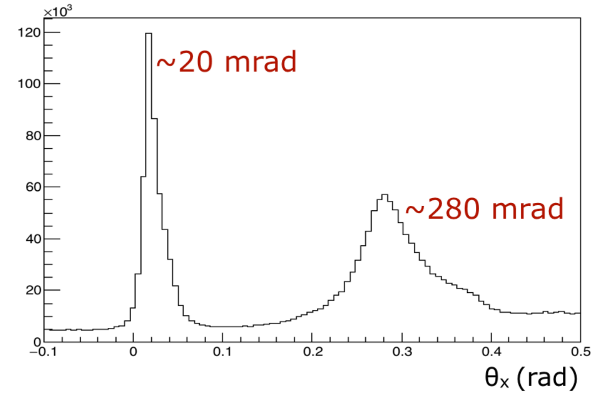
the box was enveloped in a thick layer of thermal neutron absorber

A few details from the measurements in site F:

background of ~10^7 tracks/cm^2 with random directions







peak at 20 mrad expected from muons coming straight from the IP.

Tracks populating the peak are ~10^5 /cm^2, consistent with predicted muon fluence; the Ag cluster density along the track in the peak consistent with muon.

what about the 280 mrad peak?

tracks populating this peak are ~10^6 /cm^2

Total integral consistent with RadMon measurement.

both x and y that pointed to the same region 20 m upstream the test position as source of those charged particles. An investigation by the LHC machine team confirmed it.

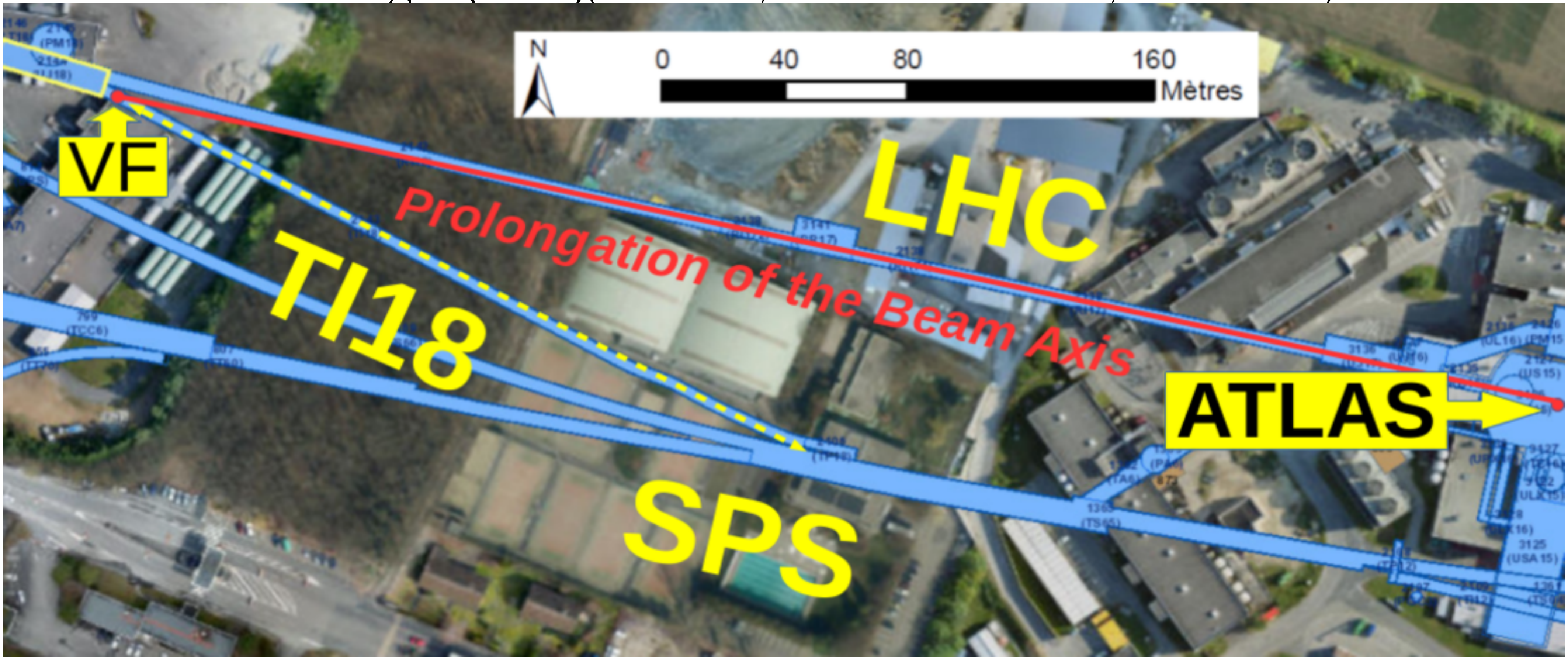
- emulsions proved to stand 10^7 tracks/cm^2
- however the plate to plate extrapolation is not possible at these rates
- safe limit: $\sim 10^5$ tracks/cm^2 , which means a limit on the exposure time depending on the local background rate

results of the measurements in the three sites along the CMS straight section:

- **muon fluence 1(6) x 10^5 /cm^2 /fb^{-1} in the F (VN) site**
- **charged hadron fluence ranges in between 10^6-10^7 /cm^2 /fb^{-1}**
- **thermal neutron fluence 10^7-10^8 /cm^2 /fb^{-1} in the best location, F**

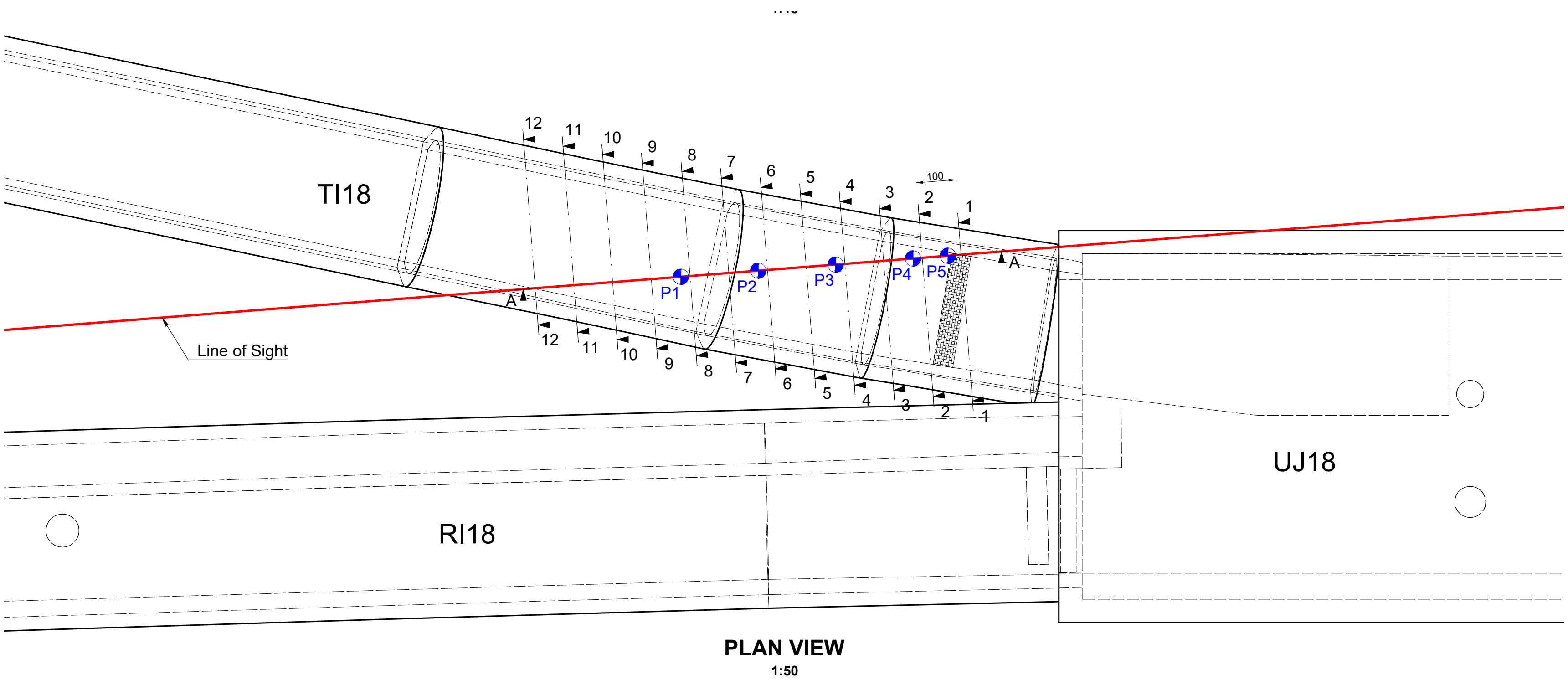
no site found good for hosting a neutrino experiment

At the same time the FASER colleagues studied a site near IP1 in view of a dark photon search experiment, centred (9.0<η<oo) on the prolongation of the beam axis of the ATLAS LHC straight section, called Line of Sight (LoS)(FASER TP, CERN LHC-2018-036, LHCC-P-013)



VF = 480 m from the IP1. It was found that the decommissioned LEP injection tunnels are quite well protected. The LoS intercepts the cavern of the TI18 tunnel after the beginning of the LHC arc.

VF (TI18) has two advantages, LHC magnetic bending and 100 m of rock, which reduce the backgrounds.



The equipment that FASER used was similar to ours, emulsion-lead package and RadMons. Since FASER has chosen to get installed in TI12, symmetric to TI18 at the opposite end of IP1, we inherited their measurements.

the FASER measurements in TI18 and TI12 show:

- muon fluence 2×10^4 /cm^2 /fb^{-1} within ~1 m around the LoS
- track density in the emulsions 3×10^5 /cm^2 after 12.5 /fb^{-1}
- charged hadron fluence below sensitivity (10^6 /cm^2)
- thermal neutron fluence 4×10^6 /cm^2 /fb^{-1}

These values are an order of magnitude lower than in the best location along the IP5 (CMS) straight section.
Exposure for 10-30 /fb is consistent with optimal tracking conditions of a few x 10^5 tracks/cm^2

The floor in the TI18 cavern slopes up

The beam LoS is under the floor from a minimum of 5 growing in steps up to 50 cm

There is no infrastructure for operating an active detector

The floor can bear a weight of up to 10 tons/m^2

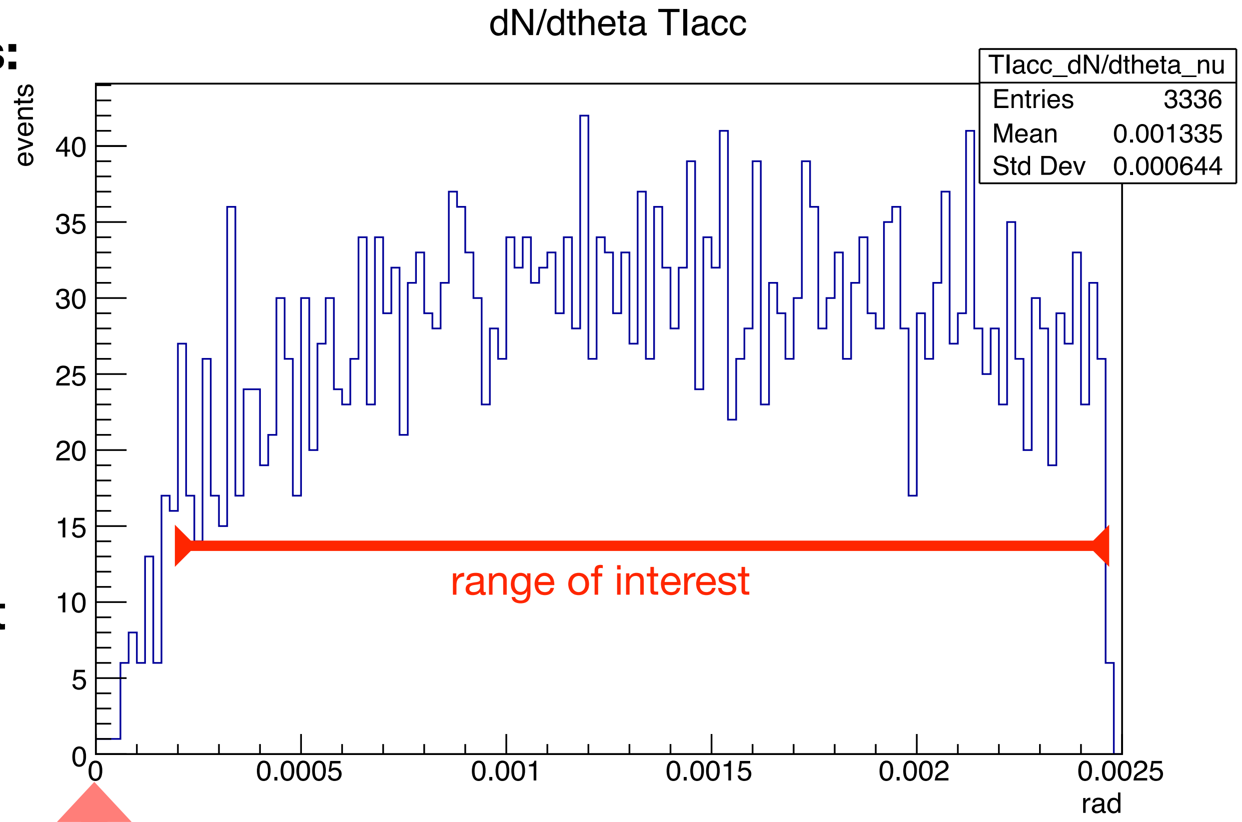
Right now, a passive emulsion-lead detector is well suited to the difficult environment.

Nuclear emulsions are an efficient detector for reconstructing the vertex of tau decays.

The floor sloping up is a bonus:

theta distribution of neutrinos from c and b decays :

detector “naturally” positioned slightly off beam axis as sought



eta	**9.2**	**8.5**	**8.1**	**7.6**	**7.0**	**6.7**
R cm	**10**	**20**	**30**	**50**	**80**	**120**

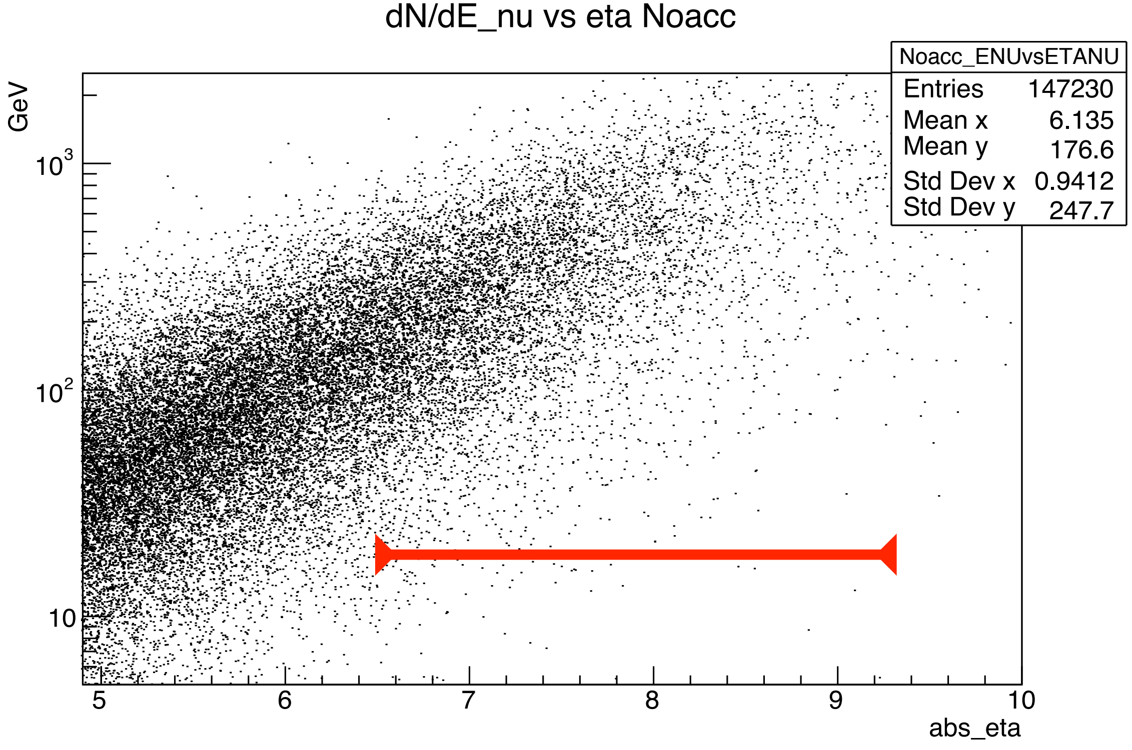
beam axis LoS

R (cm) = radial distance from beam LoS in TI18

For high energy particles from pp collisions, kinematics in the very forward direction implies that pseudorapidity and log(E) are linearly correlated, dependence smeared by the particle pt distribution

The chosen η acceptance suppresses soft energies

logE vs η scatter plot of neutrinos from c and b decays from PYTHIA pp interactions at 14 TeV



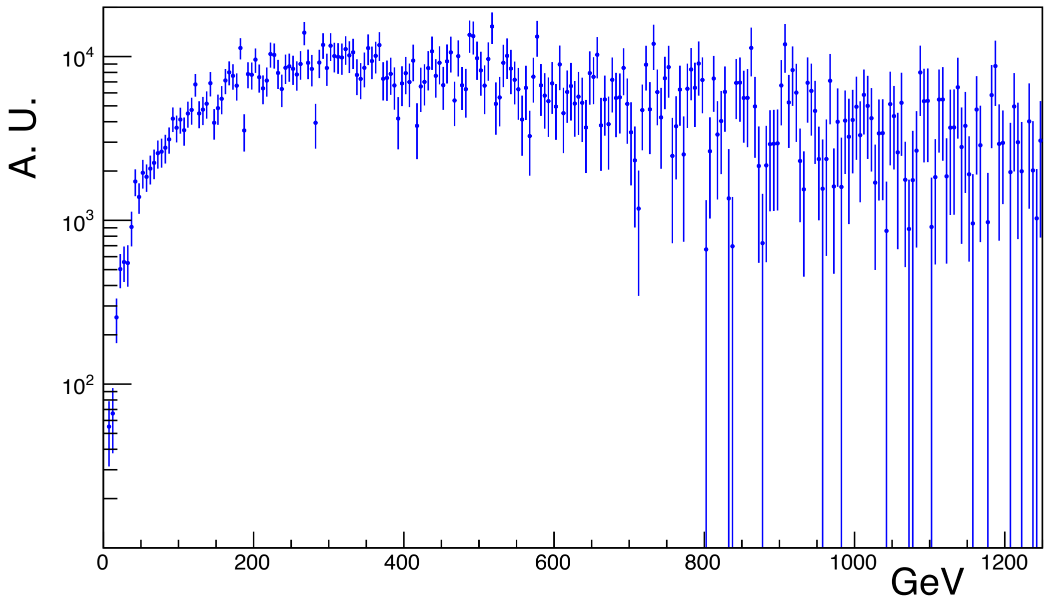
The νN cross section grows rapidly with the neutrino energy, linearly from 10 GeV to a few hundred GeV.

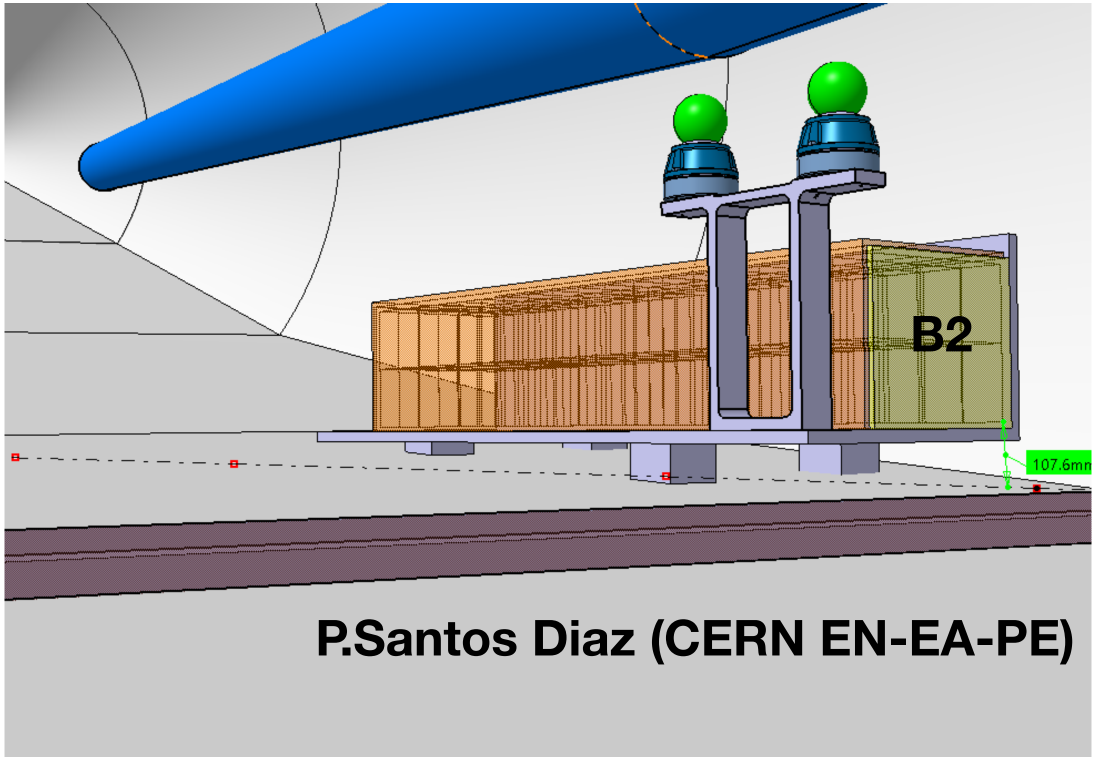
Therefore, at high energy the detector can be light, featuring a mass of a few tons, and still collect a considerable sample of neutrino interactions;

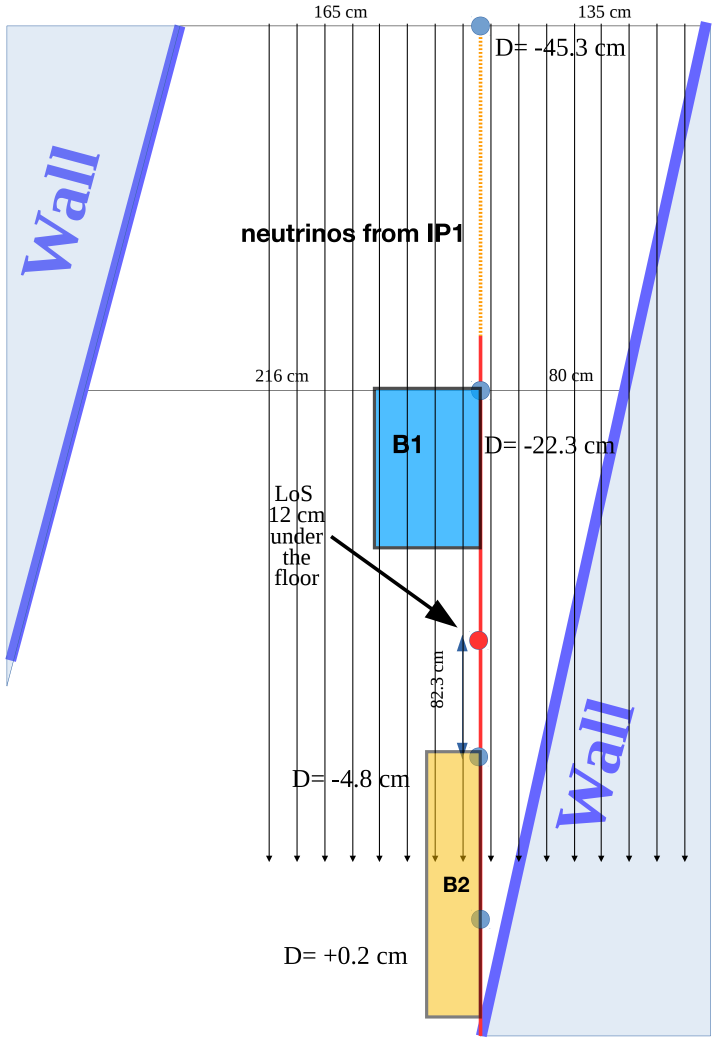
A block of lead of $30\text{x}30\text{cm}^2\text{x}1\text{m}$ weighs 1 ton.

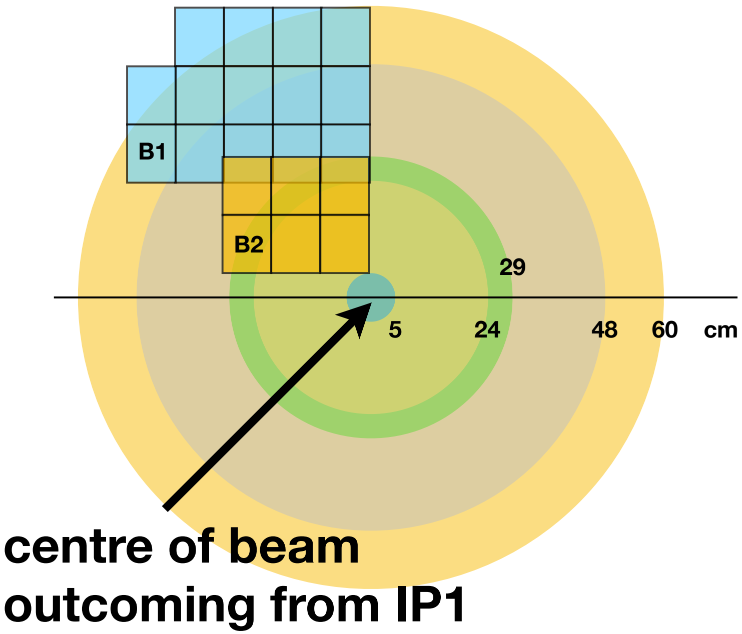
In a light detector, the energy spectrum of the observed events will be hard, because the higher energy neutrinos have larger interaction cross section.

expected energy spectrum in $\eta>6.7$ for neutrinos from c decays interacting in a 1m thick lead target









we studied an architecture with two independent detectors B2 and B1 detectors; the numbering refers to the distance from IP1.

B2 consists of 108 bricks, B1 168.

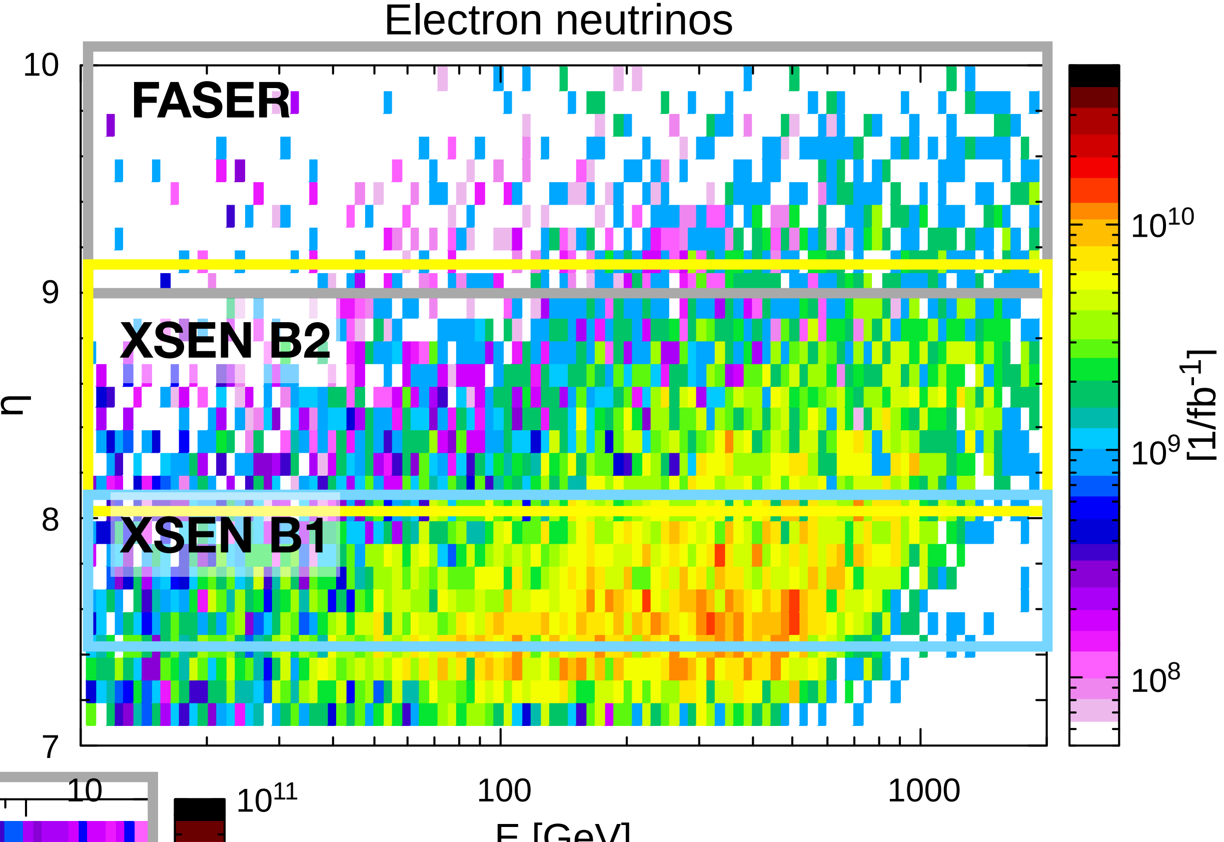
D is the height of the TI18 cavern floor from the LoS, measured in different points.

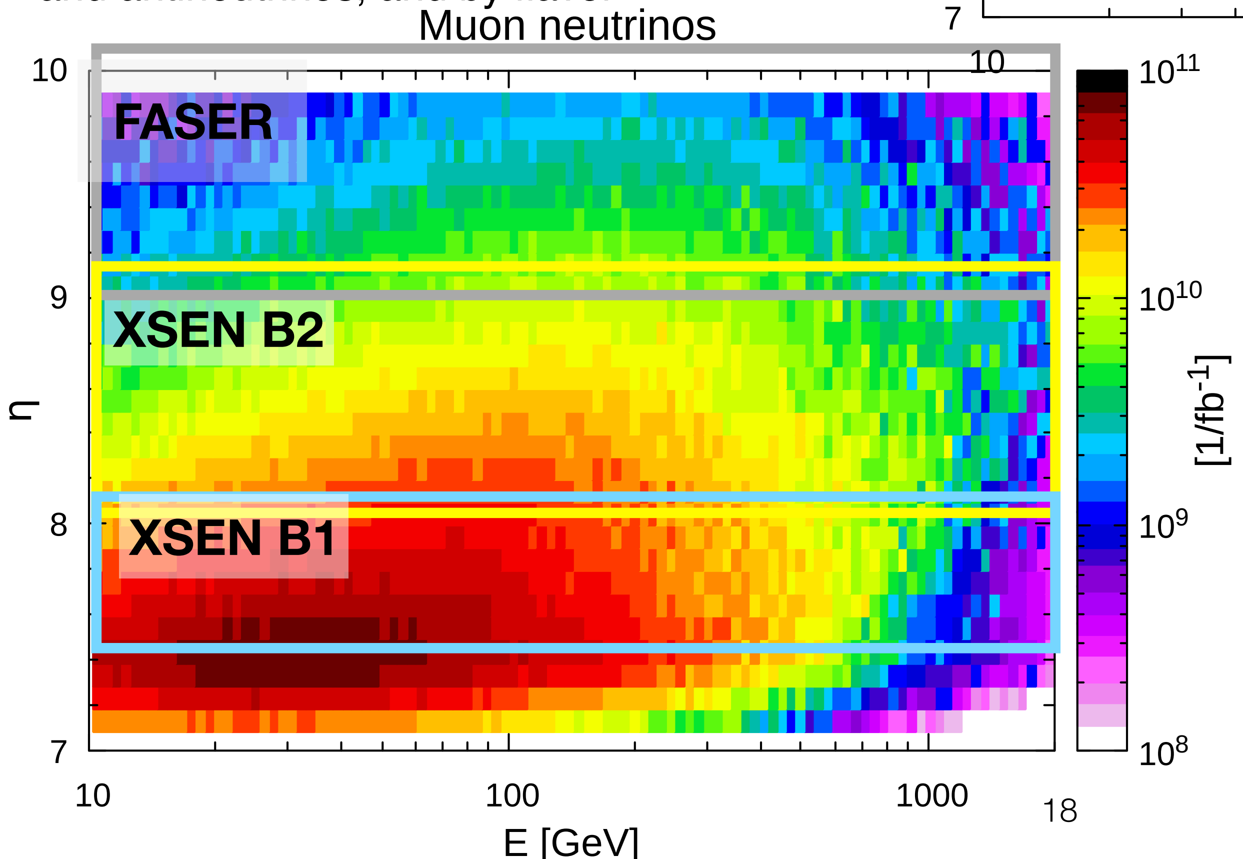
B1 and B2 radial distance in cm from the beam centre, which is taken as 57.6 mm above the LoS (120 μrad vertical Xing angle in ATLAS).

Neutrino flux in B1,B2

CERN Fluka team of EN-STI
F. Cerutti , M. Sabatè-Gilarte

— Proton-proton collisions generated with Fluka using the embedded **DPMJET** event generator, which describes **soft multiparticle production, including charm** production;
— then pions and Kaons, before decaying, were transported through LHC elements and environment material up to TI18.
— Information stored separately for neutrinos and antineutrinos, and by flavor.

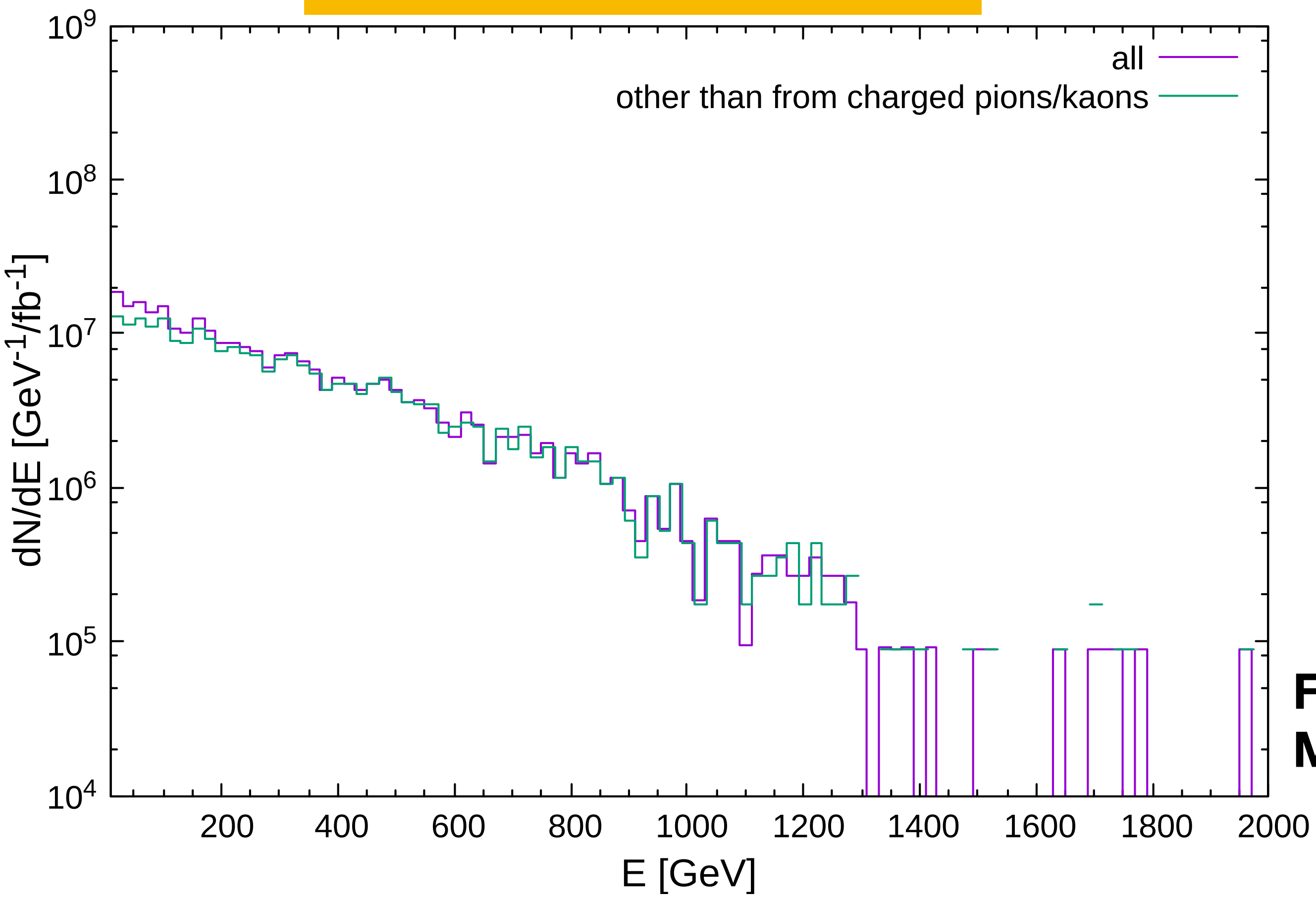




Electron neutrinos show the η-logE dependence of particles from IP

— **Muon neutrinos** from pion decays pointing towards TI18 are predicted to **peak at low energies:** pions of 10 GeV have a $\gamma c\tau$ of about 550 m, pions of 100 GeV 5.5 Km; therefore most of high energy pions are deviated by the LHC optics and interact in the LHC beam pipe or in the rock before they can decay.
—Neutrinos from Kaon decays pointing towards TI18 can have higher energies, the $\gamma c\tau$ for a 100 GeV Kaon being about 740 m, however the Kaon/pion production rate ratio is only about 11%.

Electron neutrinos 30-60 cm **(7.4<η<8.1 , B1 acceptance)**



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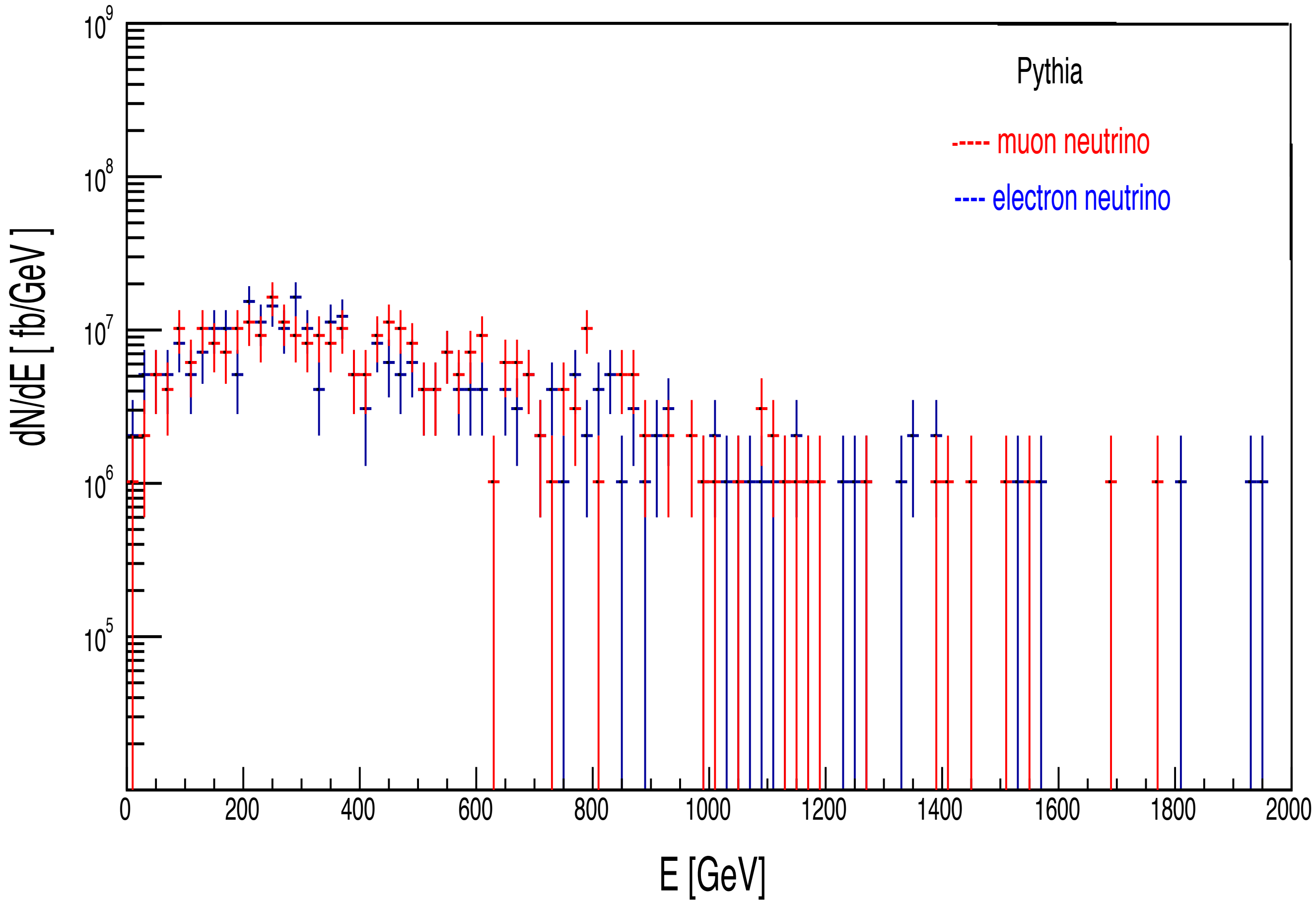
This shows that almost all electron neutrinos do not come from pion/Kaon decay. Charm production.

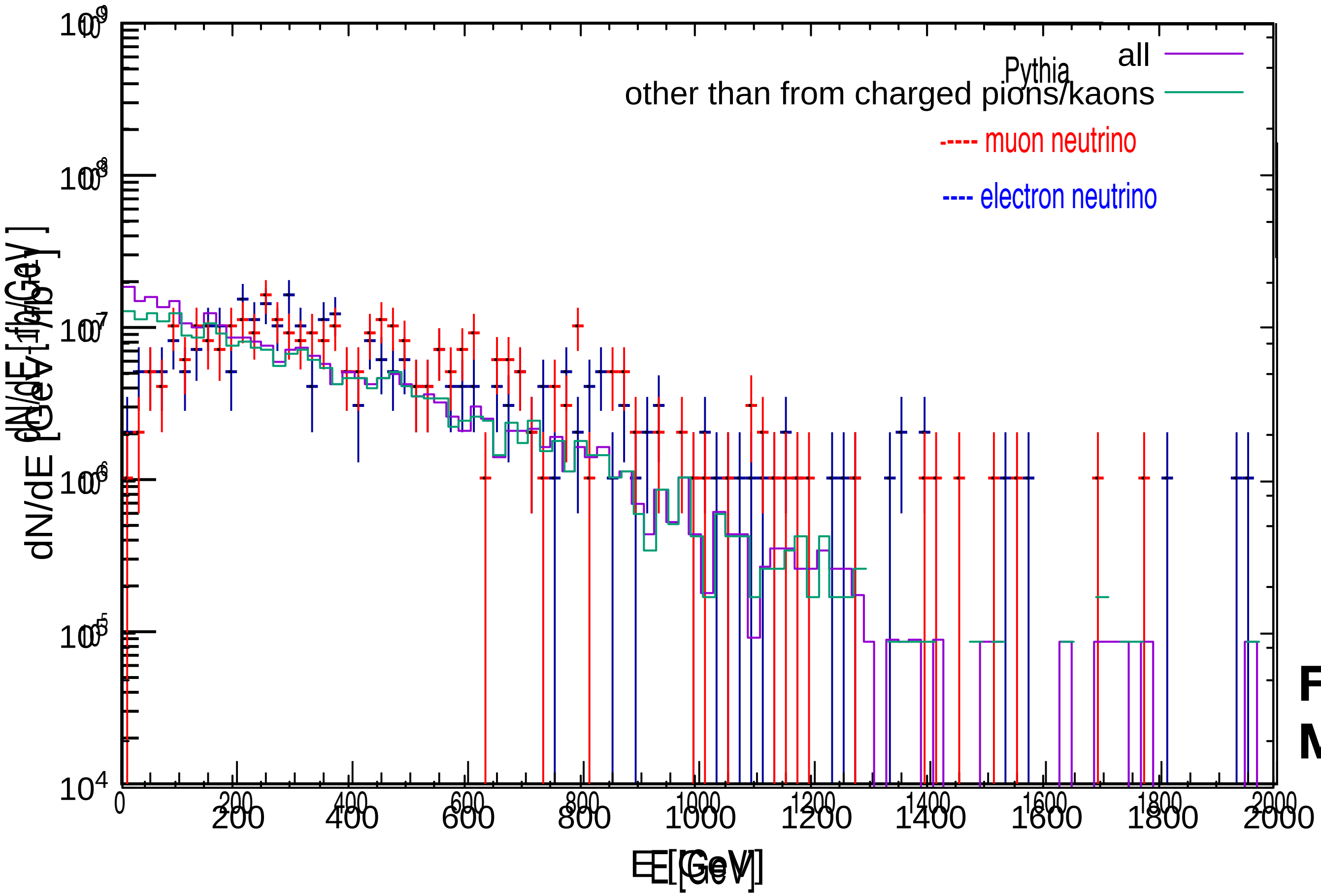
compare to flux of neutrinos from charm production in pp collision simulated with Pythia



DPMJET-Pythia comparison

shows a good agreement

Electron neutrinos 30-60 cm **(7.4<η<8.1 , B1 acceptance)**



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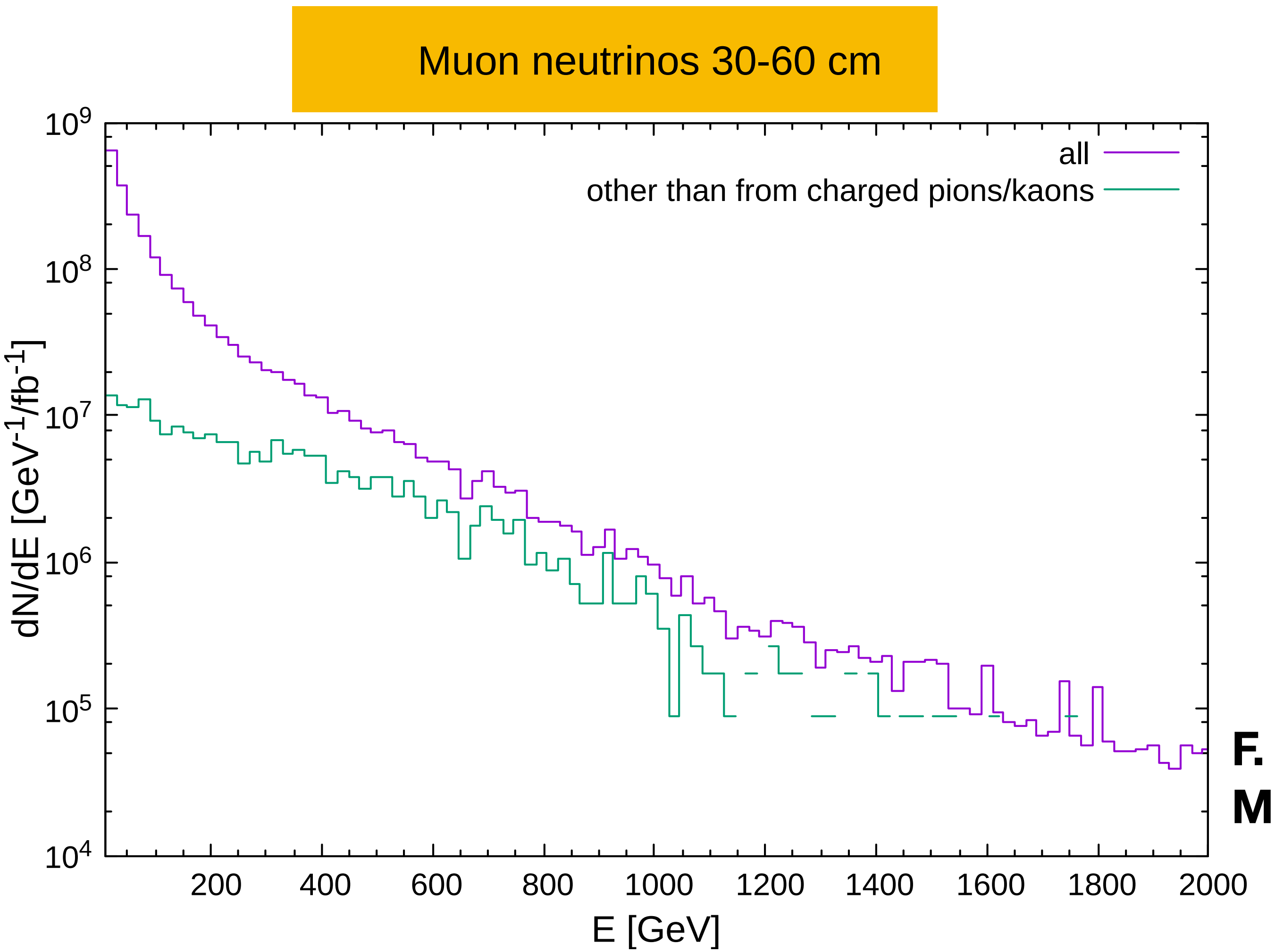
Electron neutrinos do not come from pion/Kaon decay.
Charm production.



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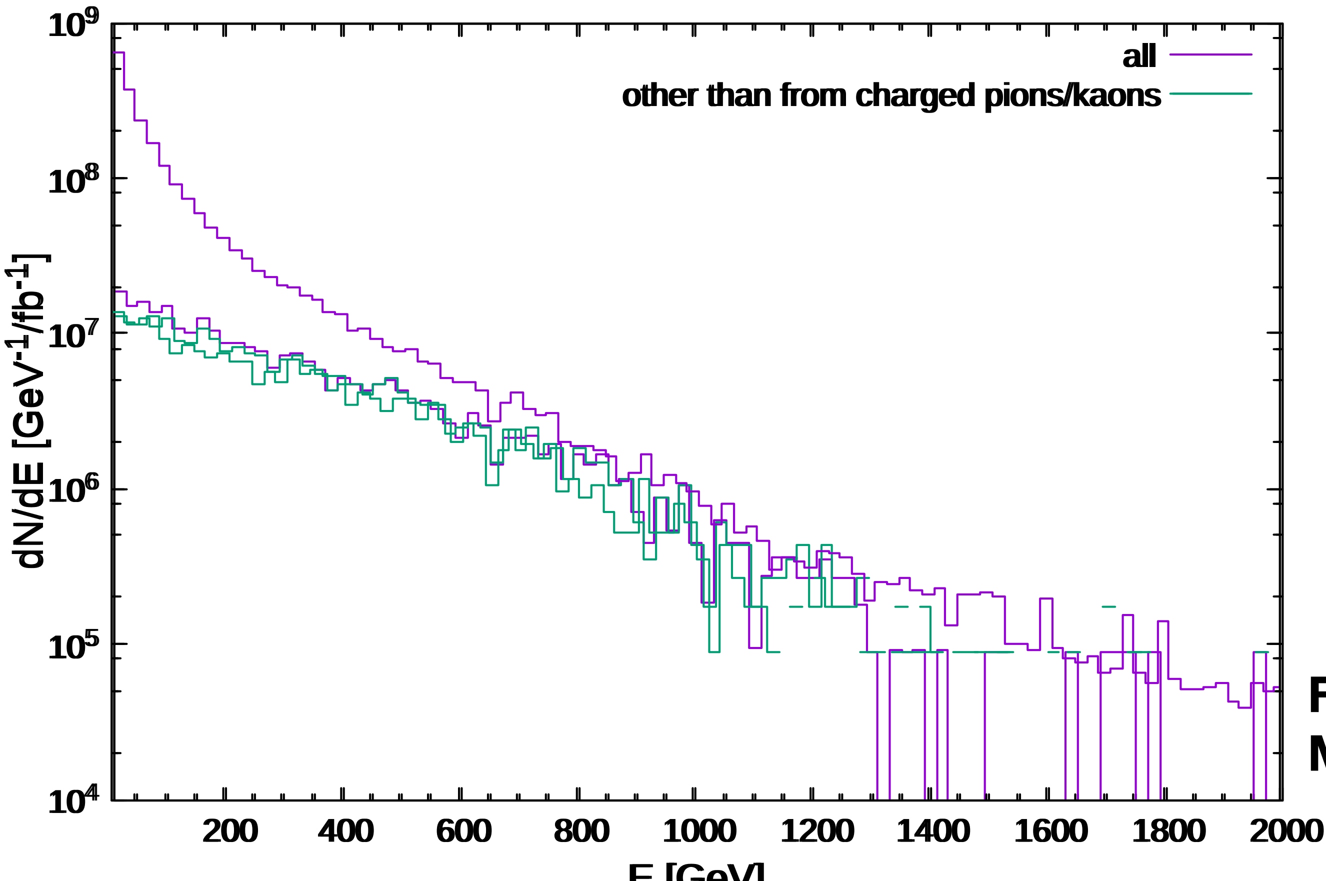
comparison of muon and electron neutrinos

(7.4<η<8.1 , B1 acceptance)



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In the B1 acceptance high energy neutrinos do not come from pion/Kaon decay.

Furthermore, the low energy component will be disfavoured in interacting with the detector and will be depleted.
Studies ongoing. Pythia uncertainty? LHC simulation uncertainties?

XSEN proposal for LHC Run3:
two steps: phase1 (2021), phase (2022/23/(24?))

Phase1: The Demonstrator
A compact detector (B2) of 0.4 to 1 ton will be built for a PILOT run to take data in 2021.

TECHNICAL PROPOSAL to be delivered to LHCC by Nov 10.
LHC expects to deliver ~25 /fb.A hundred high energy neutrino interactions can be collected.
Experience will be acquired on:

– local backgrounds. Tune simulations. Exposure time.

– emulsion handling

– analysis.

Phase2: The full bloom
The XSEN detector is extended to 1.5 and up to 3 tons, in two independent sections (B1 and B2) subtending two different eta ranges, for taking data from 2022 until the LHC Long Shutdown 3.

Possibility of Integrating and improving the apparatus with an ACTIVE DETECTOR

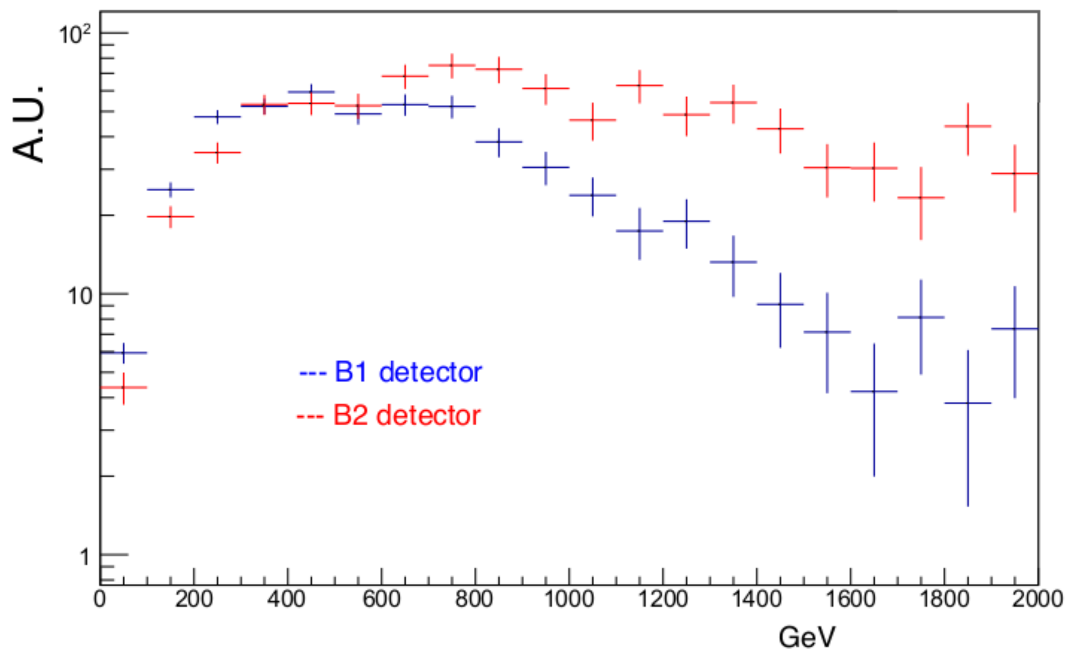
For detector construction, installation, run and analysis strategy, see presentations by :
Giovanni De Lellis   and   Dragoslav Lazic

Table 2: Expectations for a detector configuration as shown in Figure 12. B2 and B1 are made of 108 and 168 bricks respectively.

	B2 Pilot 25 /fb	B2 150 /fb	B1 150 /fb	B2+B1 150 /fb	B2+2xB1 150 /fb
integral ν fluence	5.6×10^{10}	3.4×10^{11}	4.6×10^{11}	0.8×10^{12}	1.3×10^{12}
all flavour ν events	142	852	490	1342	1832
tau flavour ν events	4	25	26	51	77
η range	8.0-9.5	8.0-9.5	7.4-8.2		
average E_ν (RMS) GeV	1200(600)	1200(600)	700(400)		
$\Delta\sigma_{\nu N}$	17%	7%	9%	6%	5%

c and b decays; additional contribution of muon neutrinos from pion and Kaon decays not included

assume efficiency 50% and systematics uncertainty as large as statistical

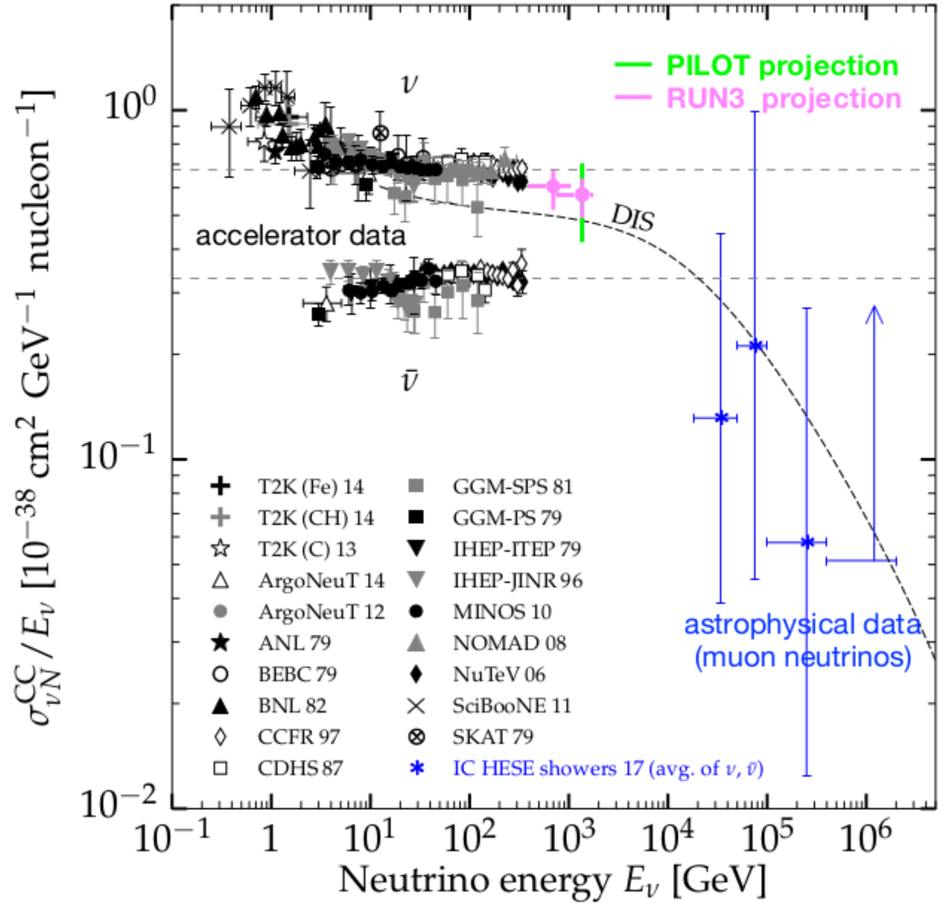


two independent energy bins

Some of the Physics issues that XSEN can tackle:

1) νN cross section measurements, also by flavor, in the 0.5-1. TeV neutrino energy range (it would need a PeV beam with a fixed target)

Bustamante M., Connolly A., arXiv:1711.11043, Jan. 12, 2019



2) measurement of pp-> ν +X cross section at √s=13 TeV for ν in 7<η<9 and neutrino flavour production Xsec ratios. Charm production and gluon PDF.