presentation of the XSEN project

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

neutrino fluxes from pp collisions at LHC and XSEN location

November 6, 2019 PBC WG meeting Marco Dallavalle (INFN Bologna)

XSEN project

It acquired weight during LHC Run2,
when the luminosity touched 2x10^{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, April 24 2019) N. Beni et al, J. Phys. G: Nucl. Part. Phys. 46 (2019) 115008

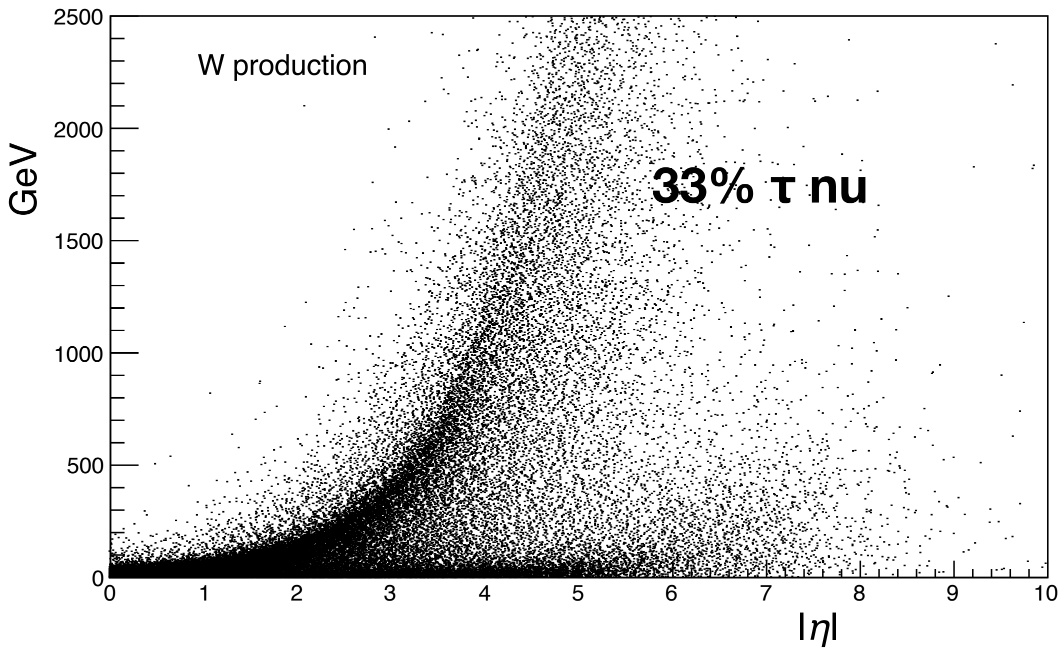
https://cds.cern.ch/record/2691399 Letter of Intent , XSEN: a νN Cross Section Measurement using High Energy Neutrinos from pp collisions at the LHC, Sep.9, 2019, CERN-LHCC-2019-014 ; LHCC-I-033
Beni, N ; Buontempo, S ; Camporesi, T ; Cerutti, F ; Dallavalle, G M ; De Lellis, G ; De Roeck, A ; De Rújula,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

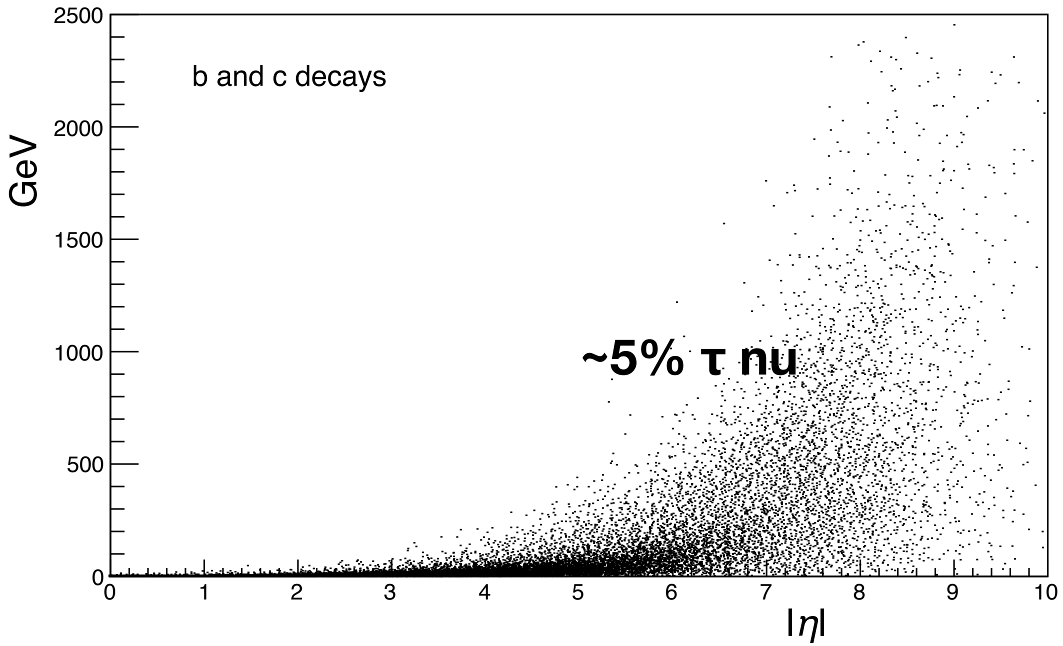
The Physics idea is 30-years old:

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.





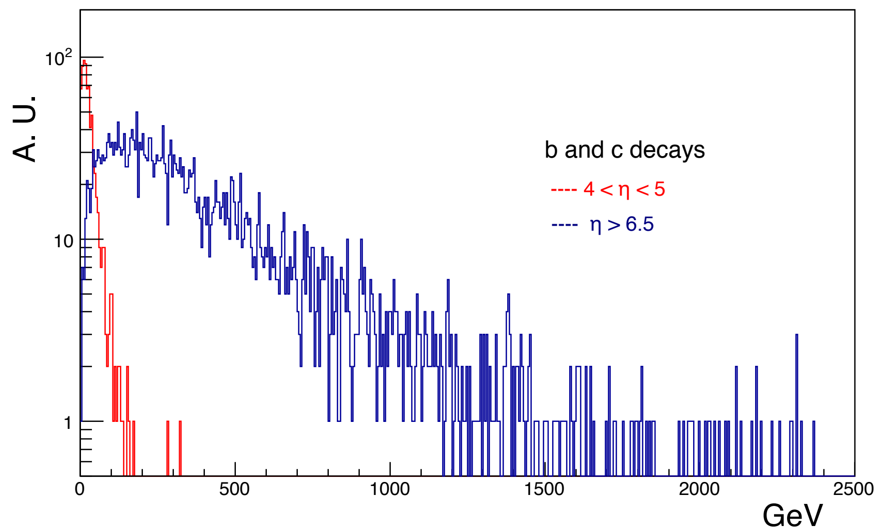
neutrino flux intensity, composition and energy depend on pseudorapity

our interest is on high energy and tau flavor

focus on two regions

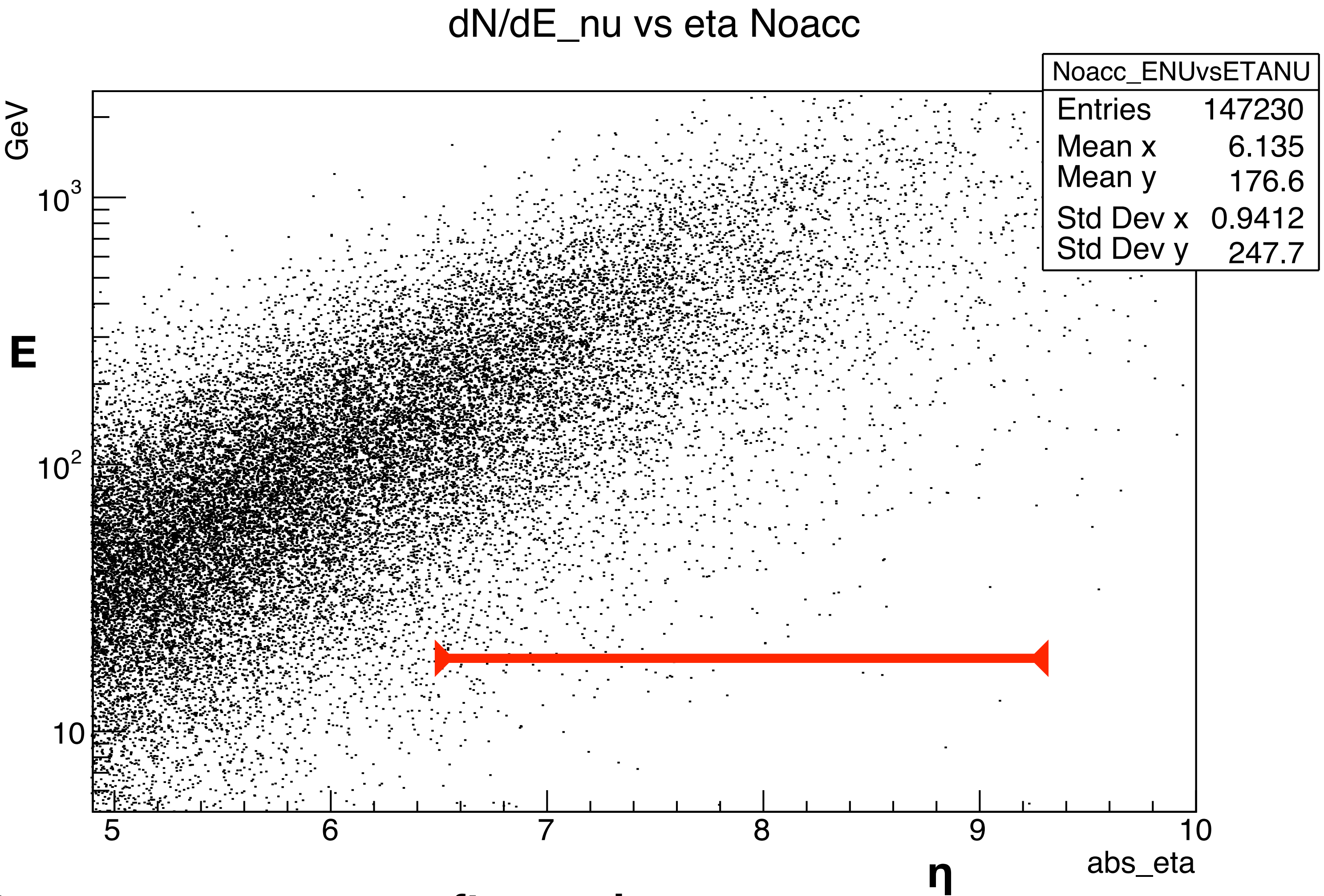
- **$4<\eta<5$ leptonic W decays (33% τ nu)**
- **$6.5<\eta<9$ c and b decays (~5% τ nu)**

a detector placed some milliradians off the beam axis



in the very forward direction pseudorapidity and log(E) are linearly correlated, dependence smeared by the particle pt distribution

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



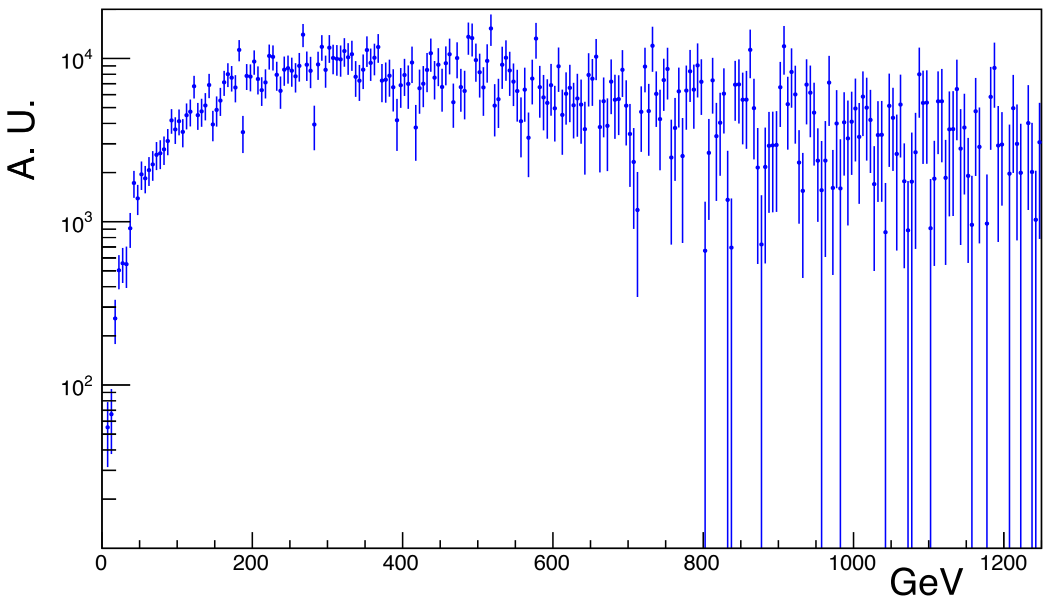
The chosen η acceptance suppresses soft energies

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

The detector can be light, featuring a mass of a few tons.

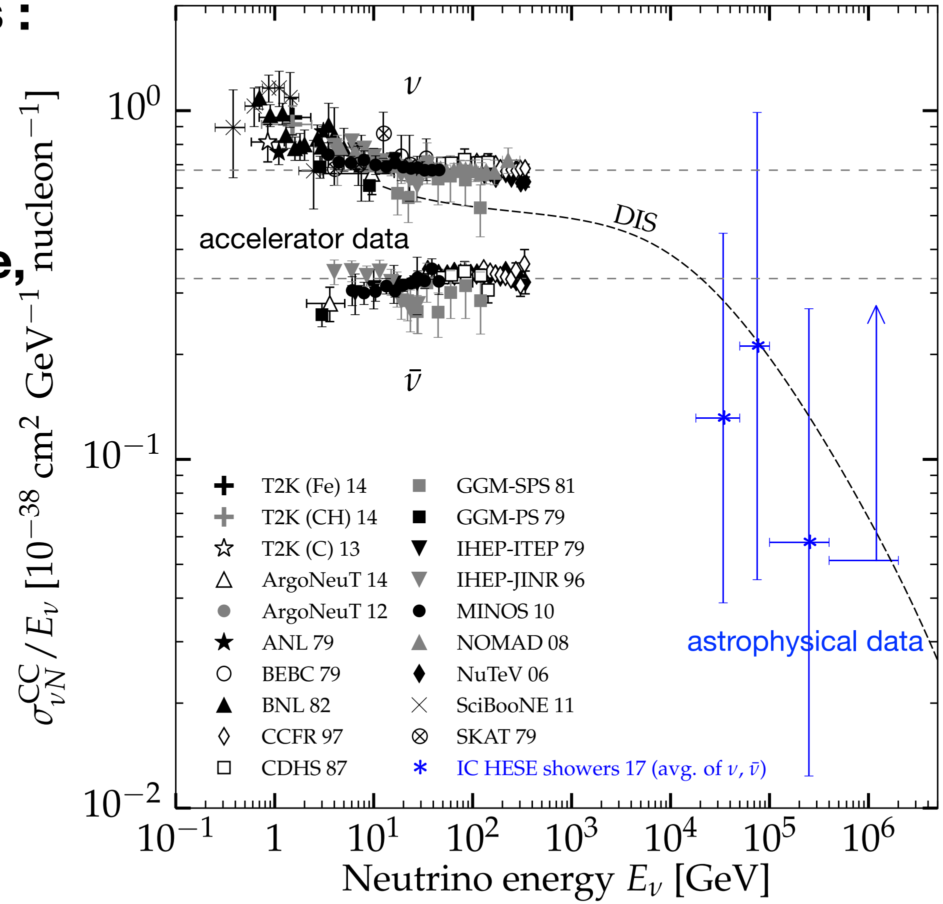
The energy spectrum of the observed events will be hard, because the higher energy neutrinos have larger interaction cross section.

expected energy spectrum in η>6.7 for neutrinos from c decays interacting in a 1 ton target



Some of the Physics issues that XSEN targets :

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



1) νN cross section measurements, also by flavor, in the 0.5-1.5 TeV neutrino energy range, unexplored

2) collect high energy tau neutrino interactions

3) measurement of pp-> ν +X cross section in $7<\eta_\nu<9$ and neutrino flavour production ratios. Charm production and gluon PDF in a new regime.

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)	

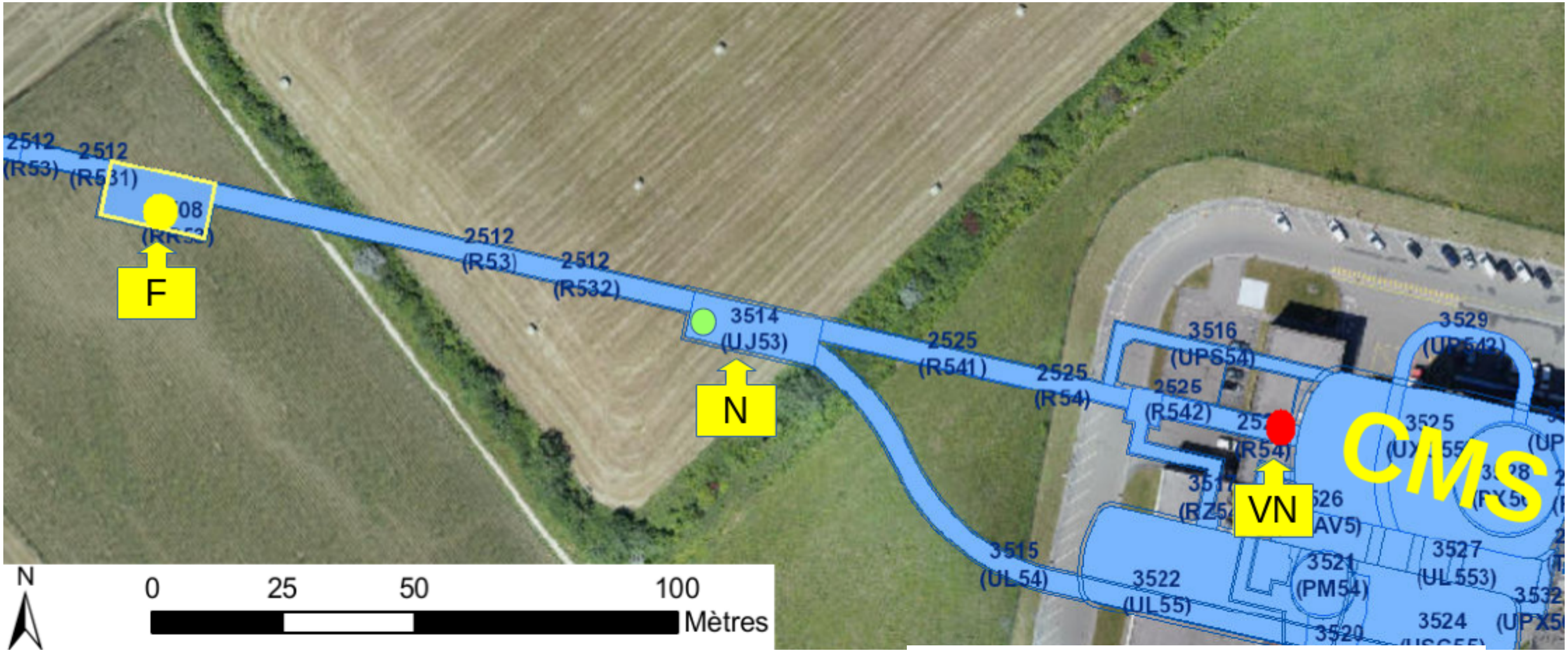
The fluence is large also when Lint =150 /fb as expected in LHC run 3

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

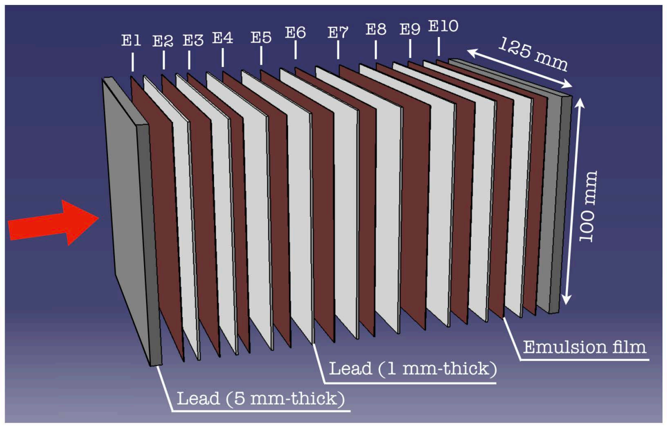
chosen sites:

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)



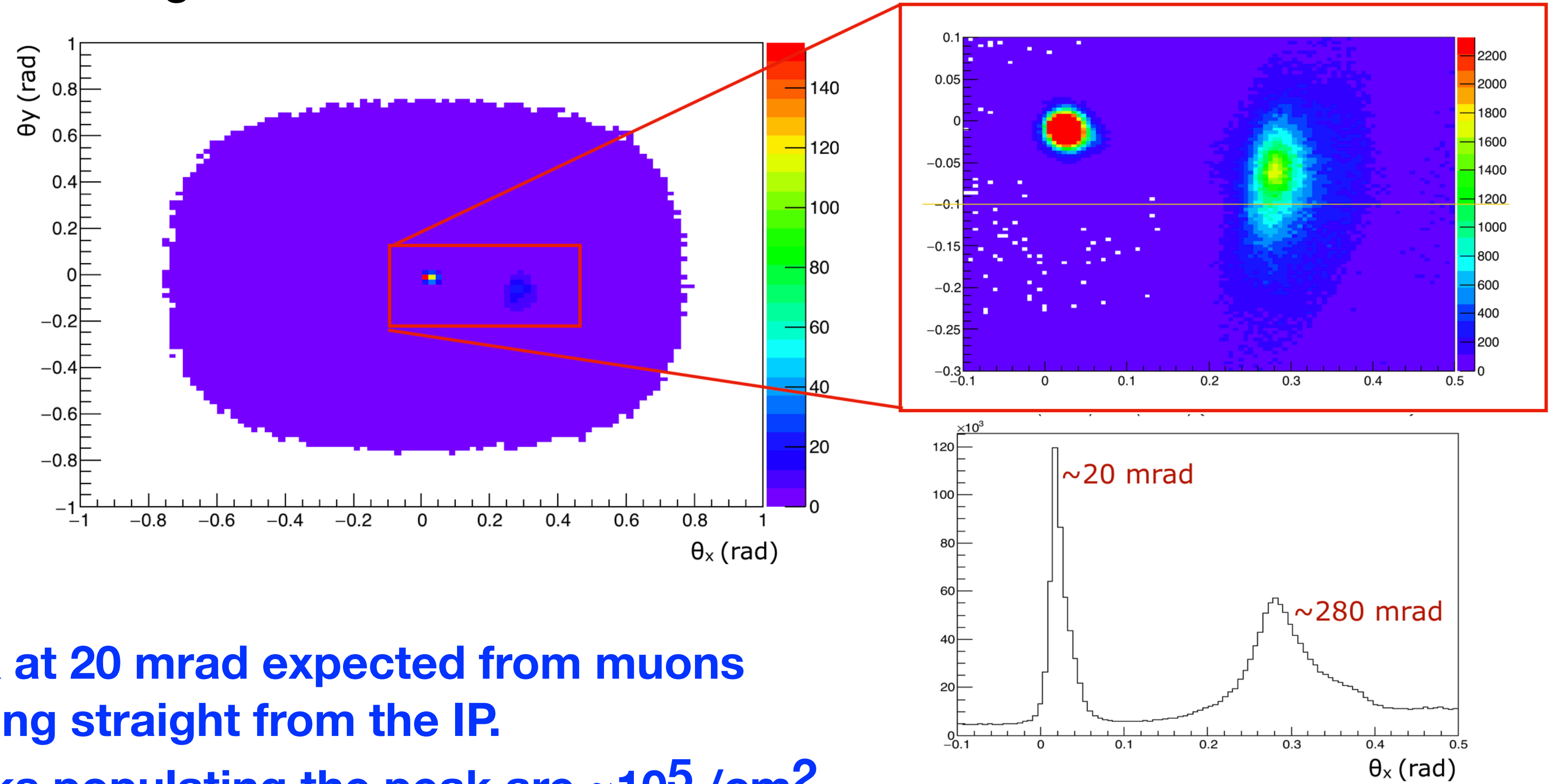
TREX and LMC gave green light with a limitation:
the test detector should not interfere with LHC

use nuclear emulsions interleaved with thin layers of lead as in the OPERA "bricks".



Example: 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

what about the 280 mrad peak?

both x and y pointed to the same region 20 m upstream 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: ~10^5 tracks/cm^2 , which means a limit on the exposure time depending on the local background rate

Also CERN Radiation Monitors were deployed to complement and cross-check emulsions.

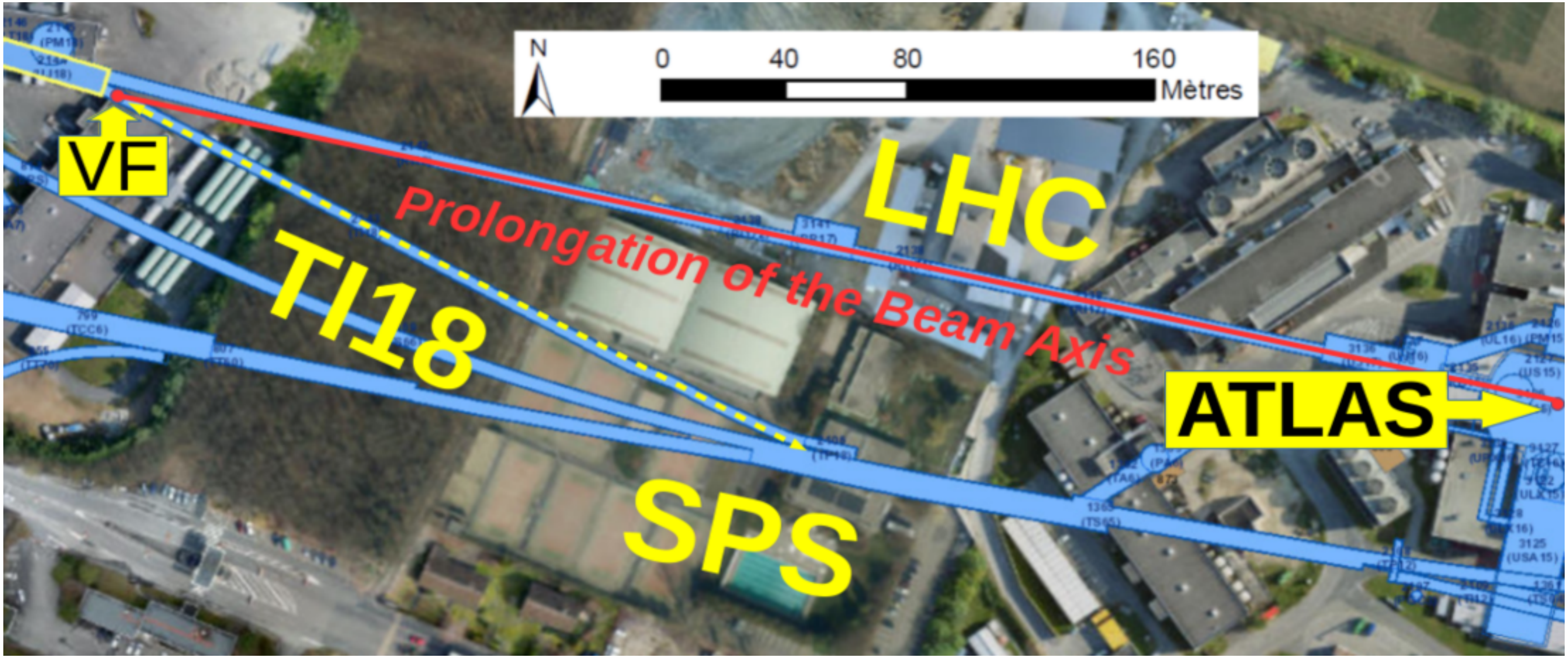
Results of the measurements in the three sites along the CMS straight section showed that

- **no site was good for hosting a neutrino experiment**

- **Good agreement with the LHC machine simulations of the CERN FLUKA team in the EN-STI group (F.Cerutti et al.)**

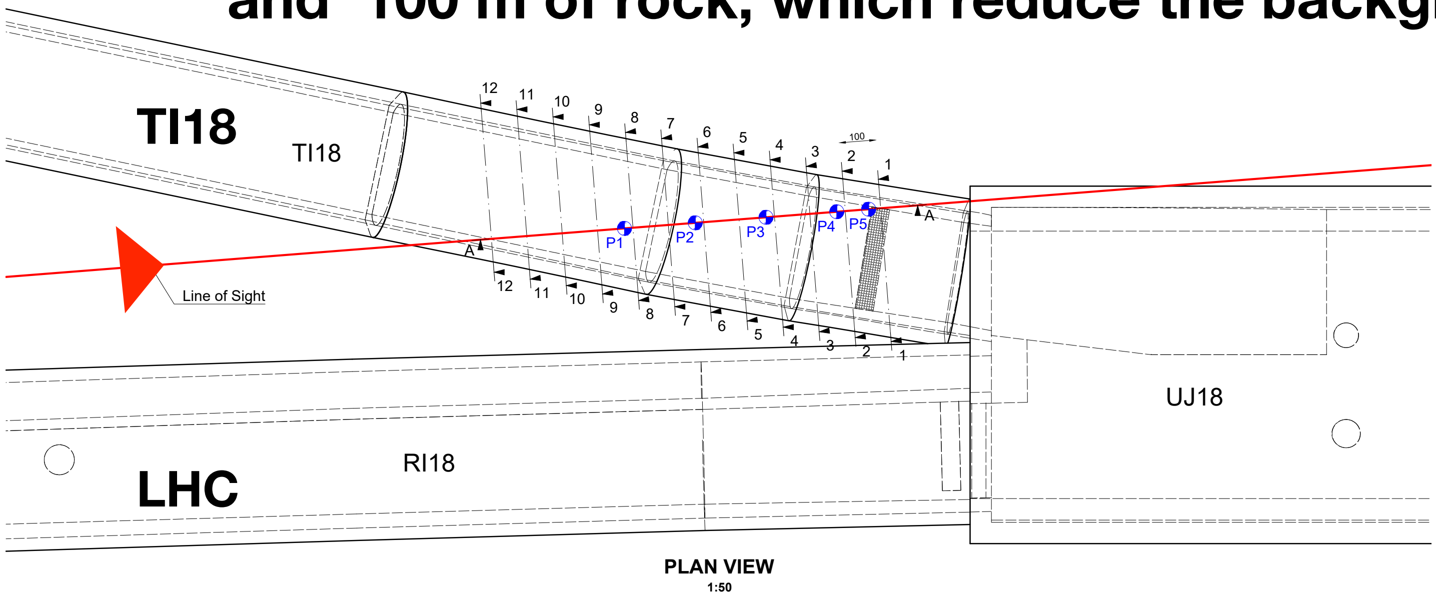
At the same time the FASER colleagues studied a site 480 m from the IP1 (FASER TP, CERN LHC-2018-036, LHCC-P-013), **(VF in the picture)**

where the prolongation of the beam axis (Line of Sight) of the ATLAS LHC straight section intercepts the cavern of the decommissioned LEP injection tunnel TI18 after the beginning of the LHC arc.



The decommissioned LEP injection tunnels only exists near IP1.

The site has two advantages, LHC magnetic bending and 100 m of rock, which reduce the backgrounds.



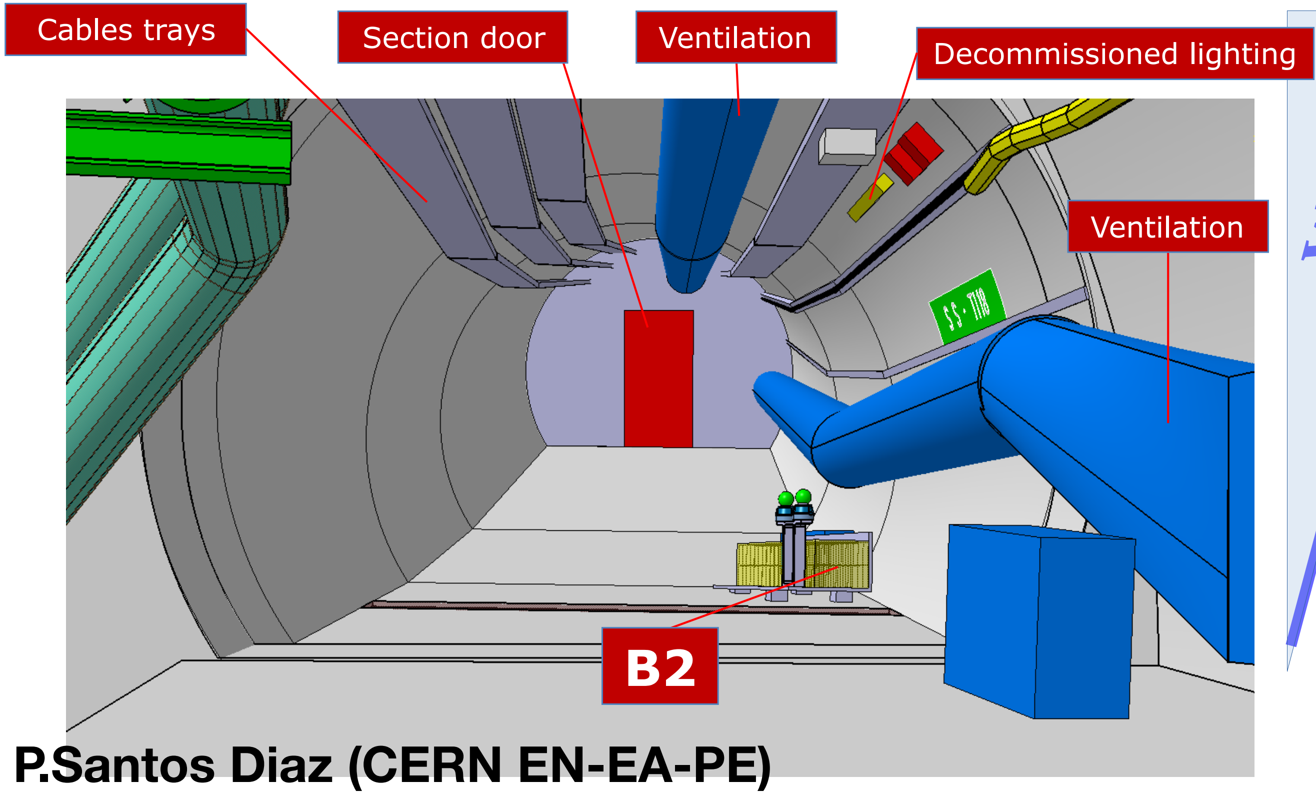
The backgrounds are an order of magnitude lower than in the best location along the IP5 (CMS) straight section.
Emulsion exposure for 10-30 /fb is consistent with optimal tracking conditions of a few x 10^5 tracks/cm^2

FASER has finally chosen to get installed in TI12, similar to TI18 at the opposite end of IP1.

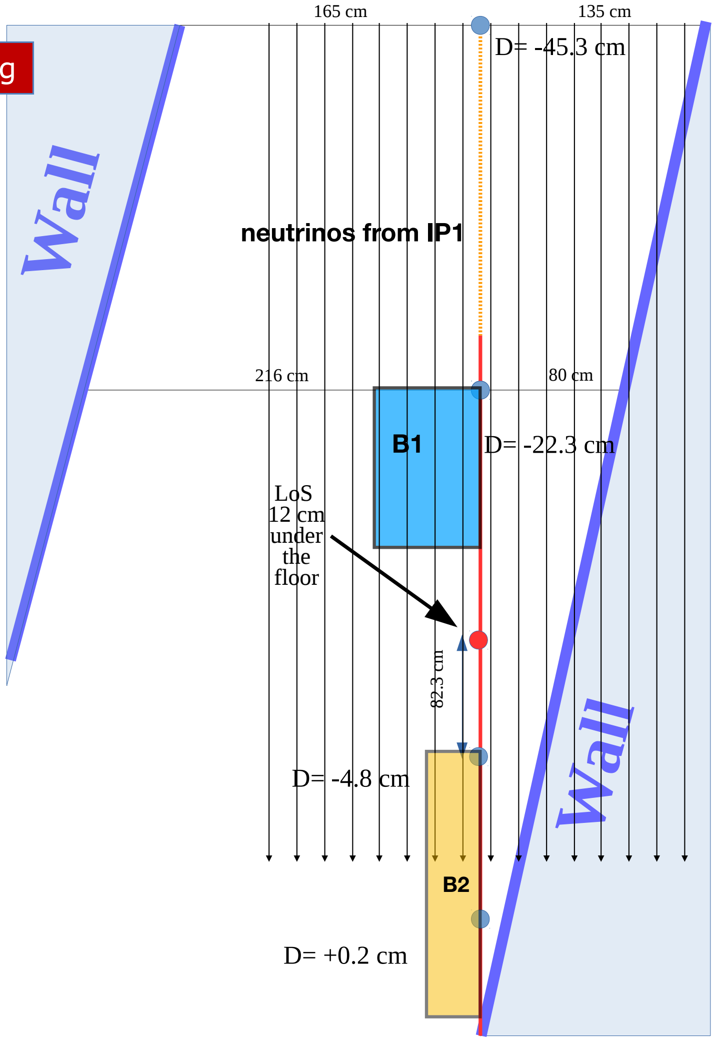
The floor in the TI18 cavern slopes up

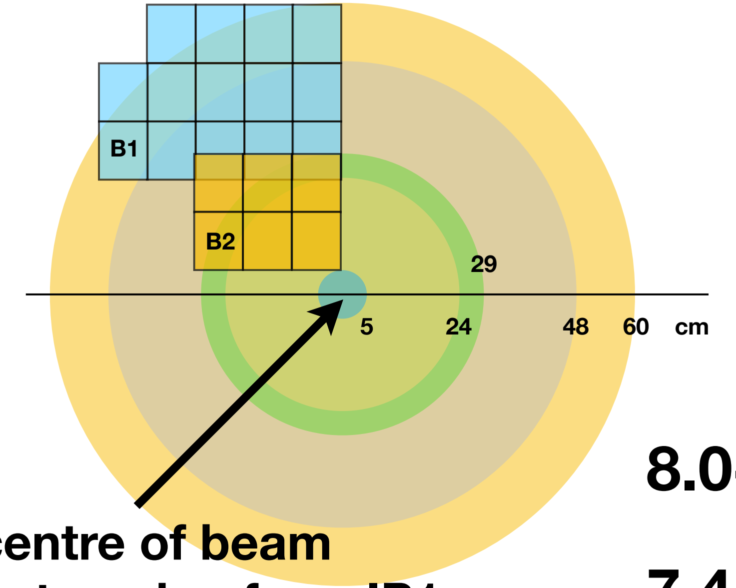
The beam LoS is under the floor from a minimum of 5 growing in steps up to 50 cm

There is no infrastructure for operating an active detector.



P.Santos Diaz (CERN EN-EA-PE)





centre of beam outcoming from IP1

B2

$8.0<\eta_{B2}<9.2$

$7.4<\eta_{B1}<8.1$

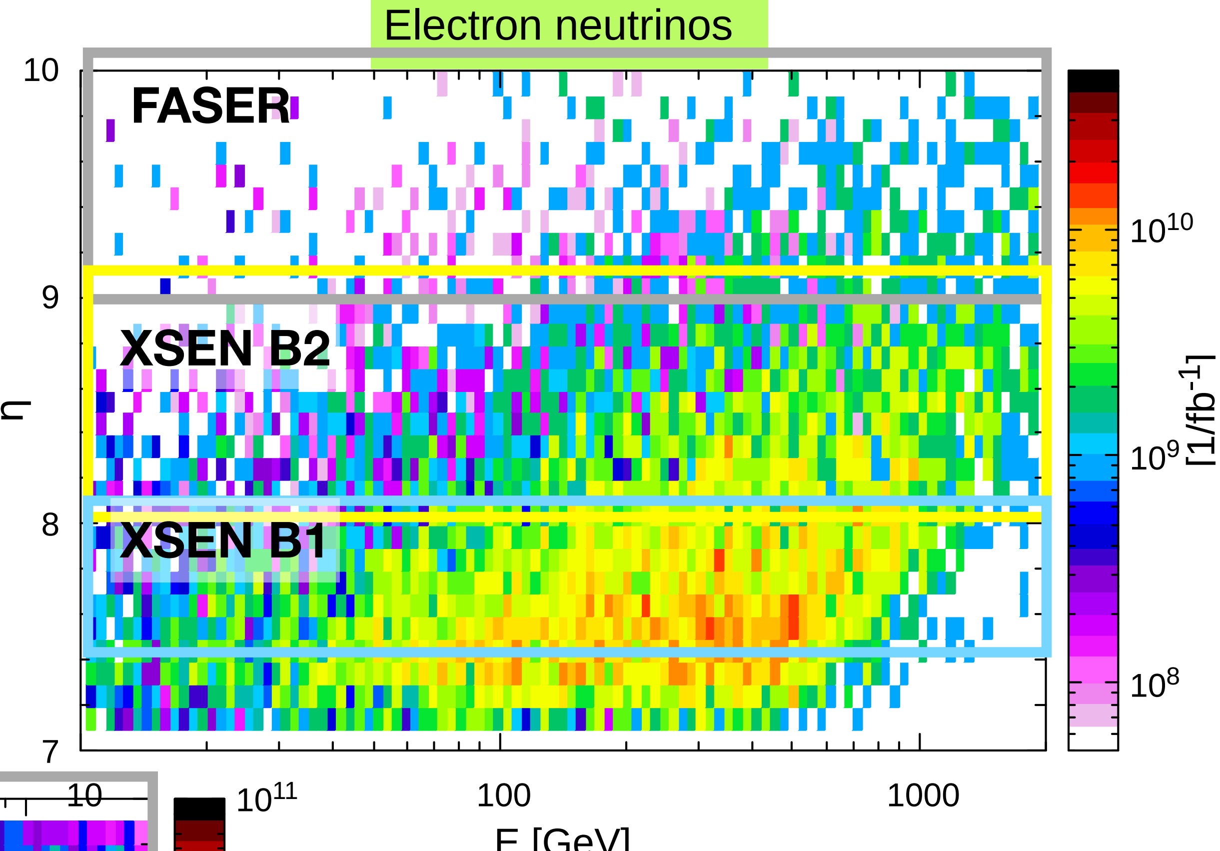
Nuclear emulsions are an efficient detector for reconstructing the vertex of tau decays.

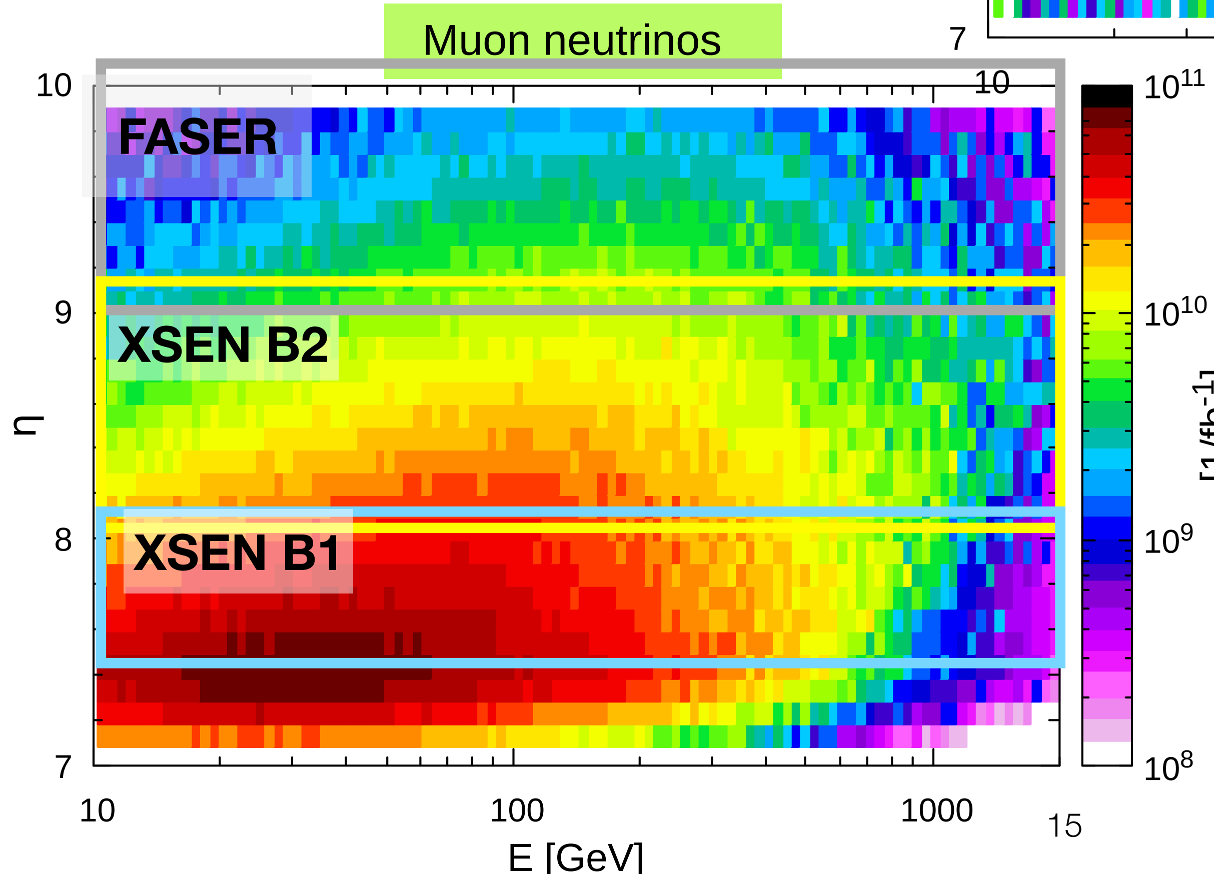
we studied an architecture with two independent detectors B2 and B1. B2 consists of 108 OPERA bricks, B1 168.

Neutrino flux in B1,B2

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

— Proton-proton collisions generated with **DPMJET** (FLUKA), which describes **soft multiparticle production, including charm**
— pions and Kaons are transported through LHC elements and environment material up to TI18.

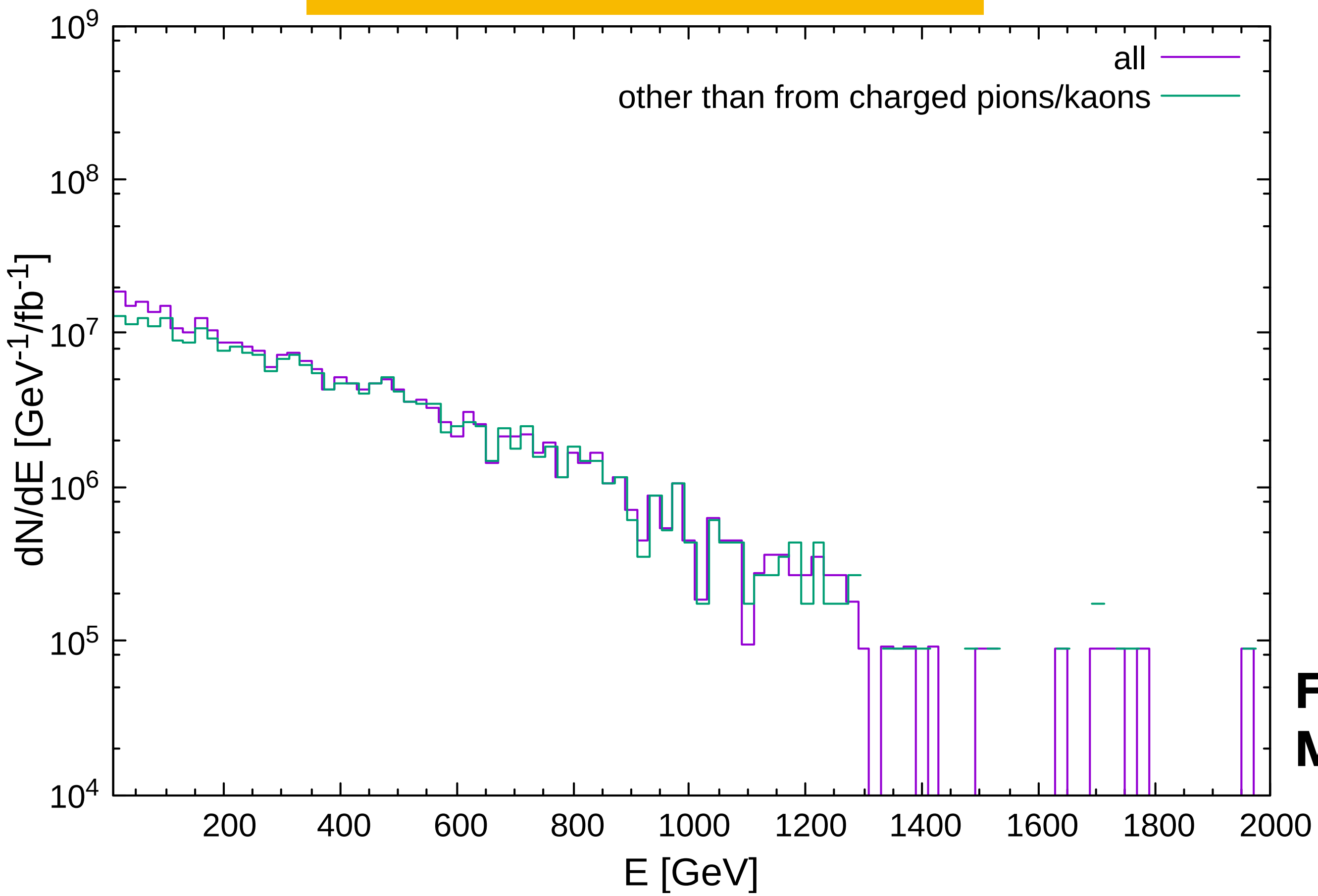




Electron neutrinos show the η-logE dependence of particles from IP

– **Muon neutrinos** from pion decays pointing towards TI18 are predicted to **peak at low energies:** pions of 100 GeV have a $\gamma c\tau$ of about 5.5 Km; therefore most of high energy pions interact in the LHC beam pipe or in the rock before they can decay.

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



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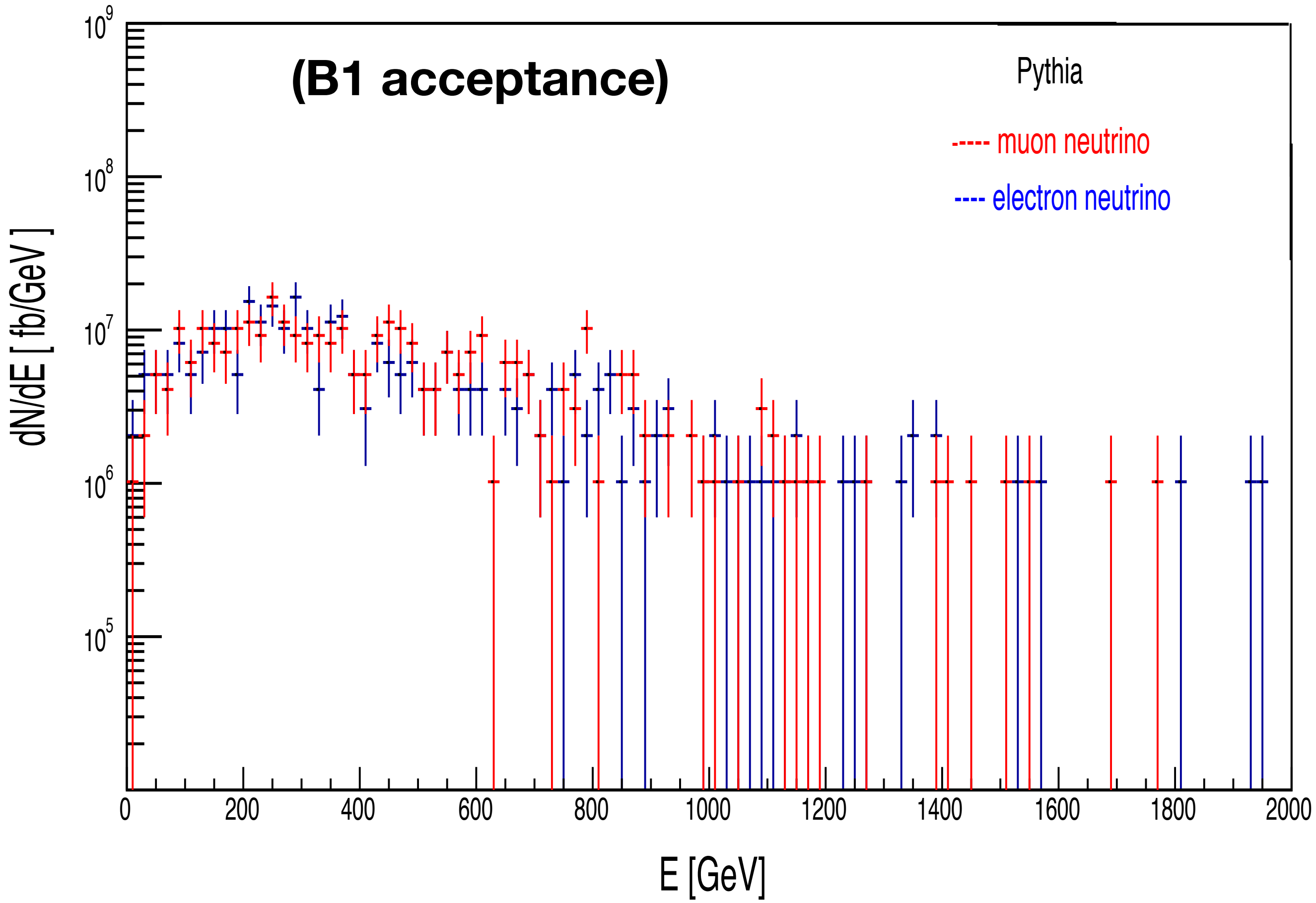
Almost all electron neutrinos do not come from pion/Kaon decay.
Charm production.

compare to flux of neutrinos from charm (and beauty) production in pp collision simulated with Pythia

b/c ~ 3% for ν_e and ν_μ

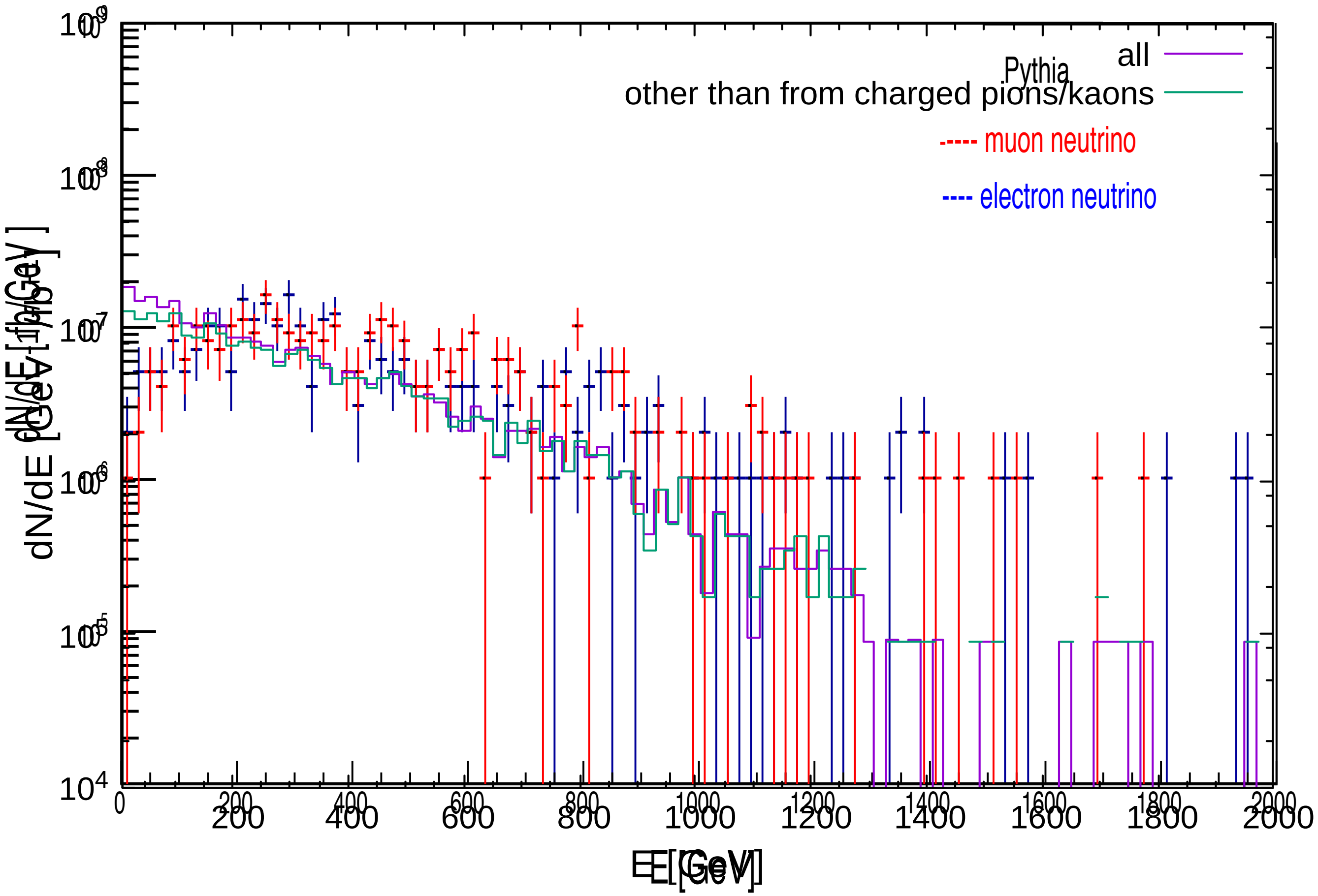
b/c ~ 8% for ν_τ



DPMJET-Pythia comparison

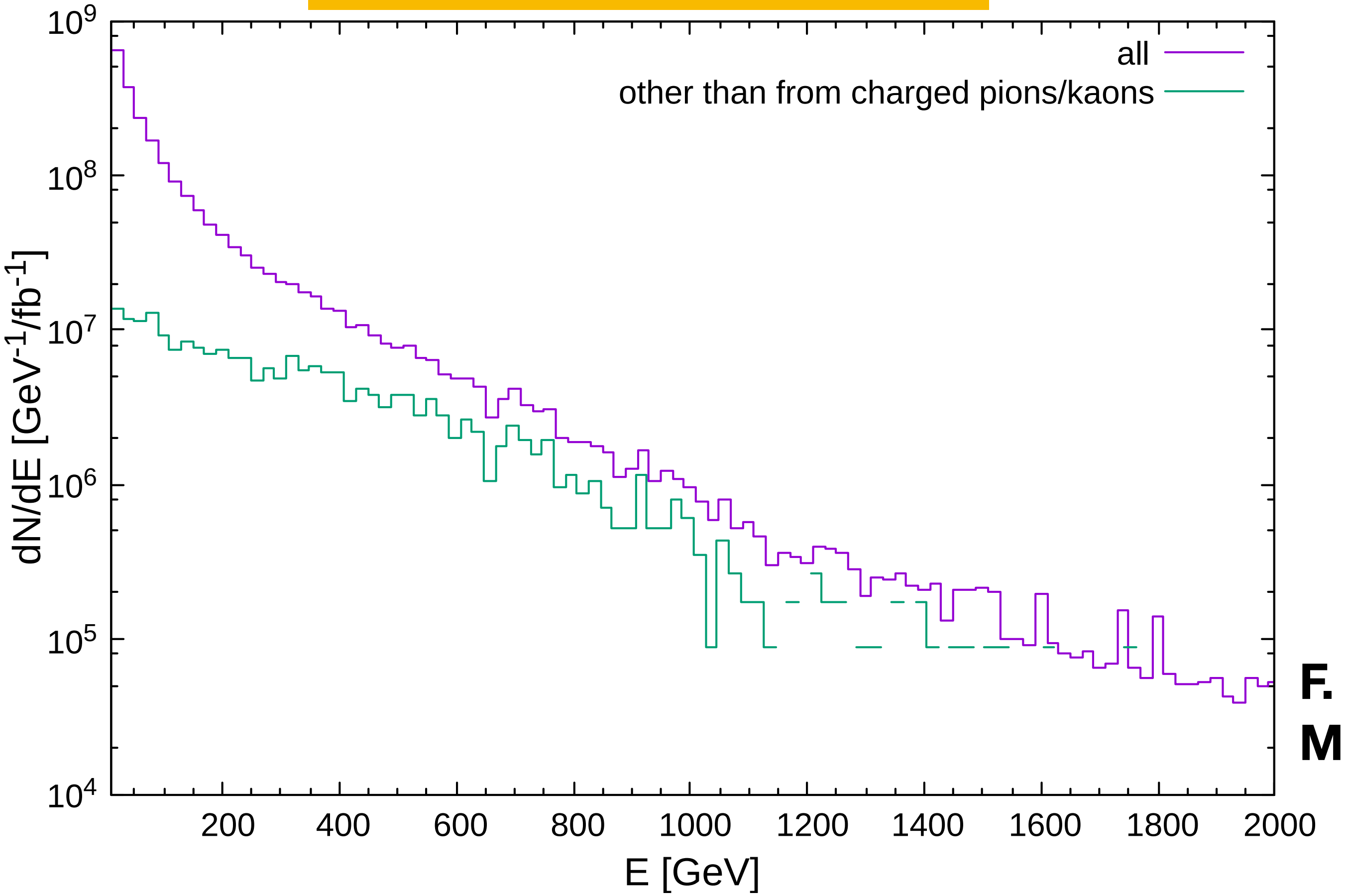
shows a good agreement

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



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

Muon neutrinos 30-60 cm



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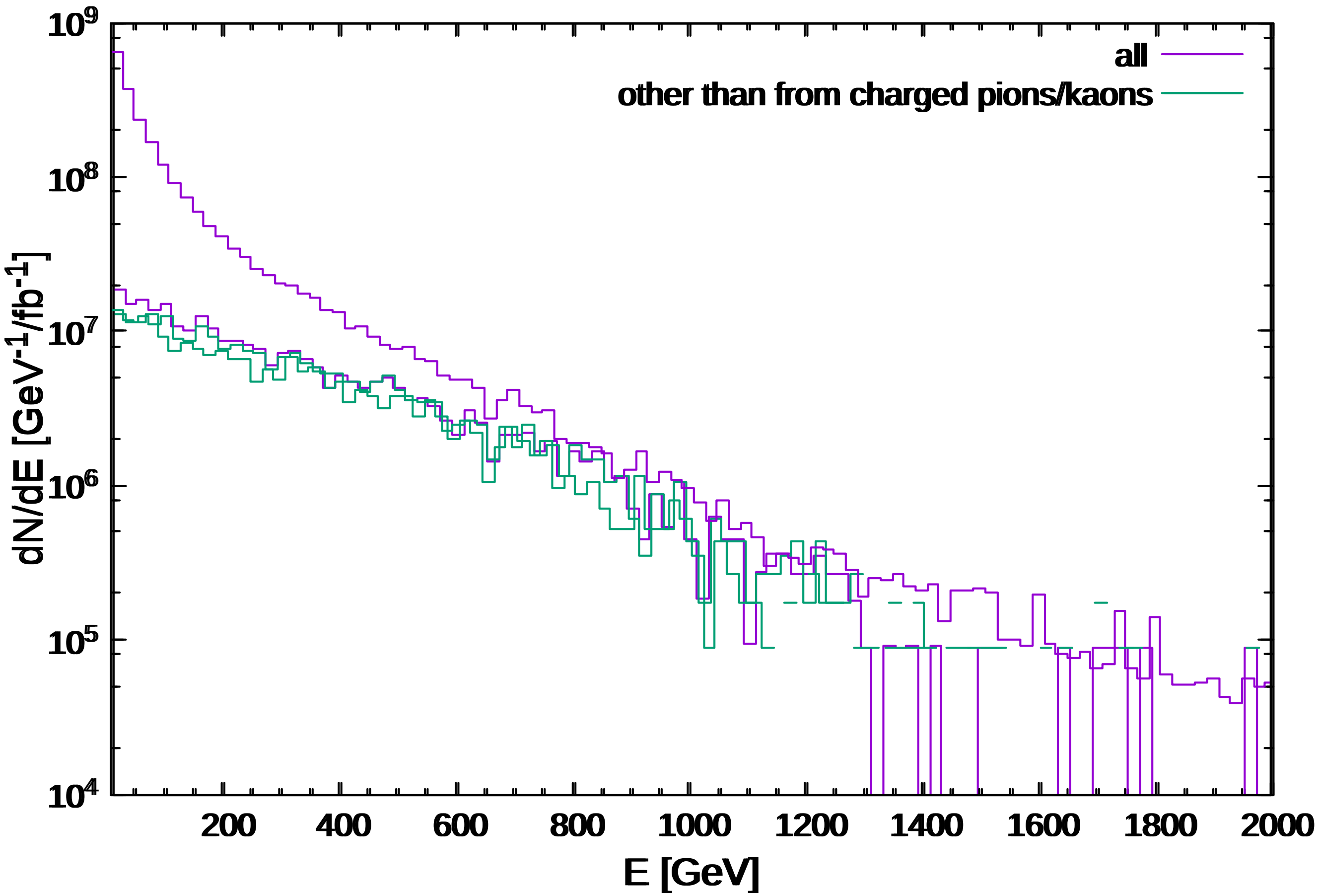
M. Sabatè-Gilarte

comparison of muon and electron neutrinos

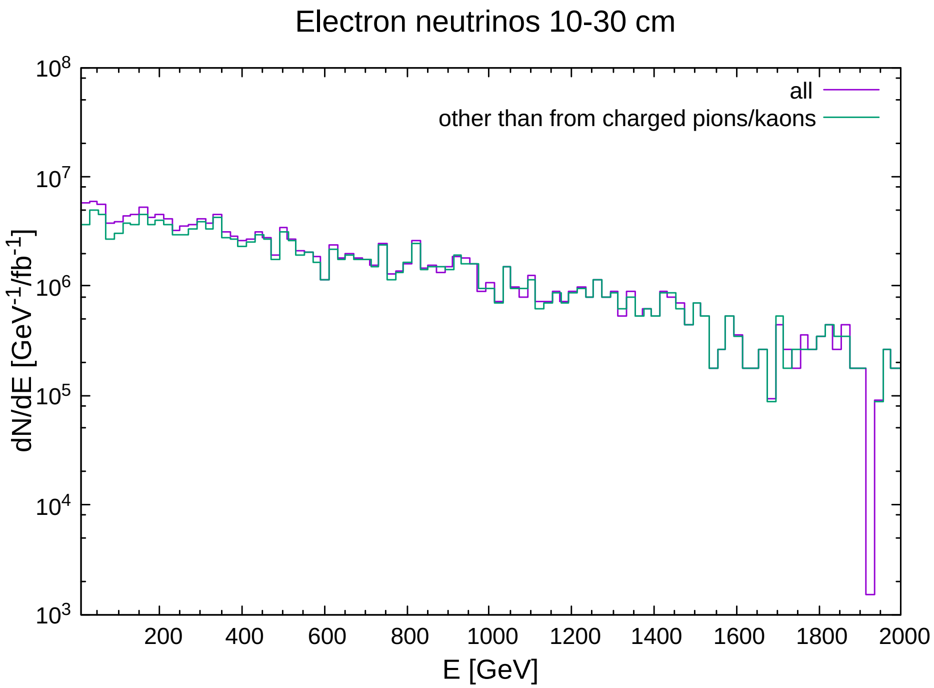
Electron neutrinos 30-60cm / Muon neutrinos 30-60cm **(7.4<η<8.1 , B1 acceptance)**

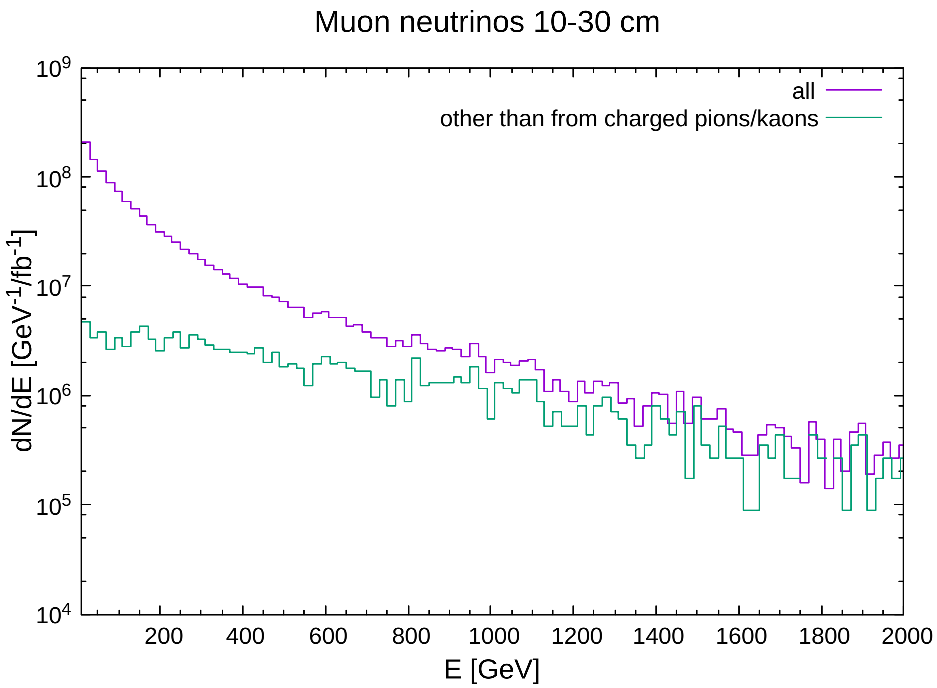


In the B1 acceptance high energy neutrinos do not come from pion/Kaon decay.

Furthermore, the low energy component will be disfavoured in interacting with the detector.

similary for 8.0<η<9.2 (B2 acceptance)





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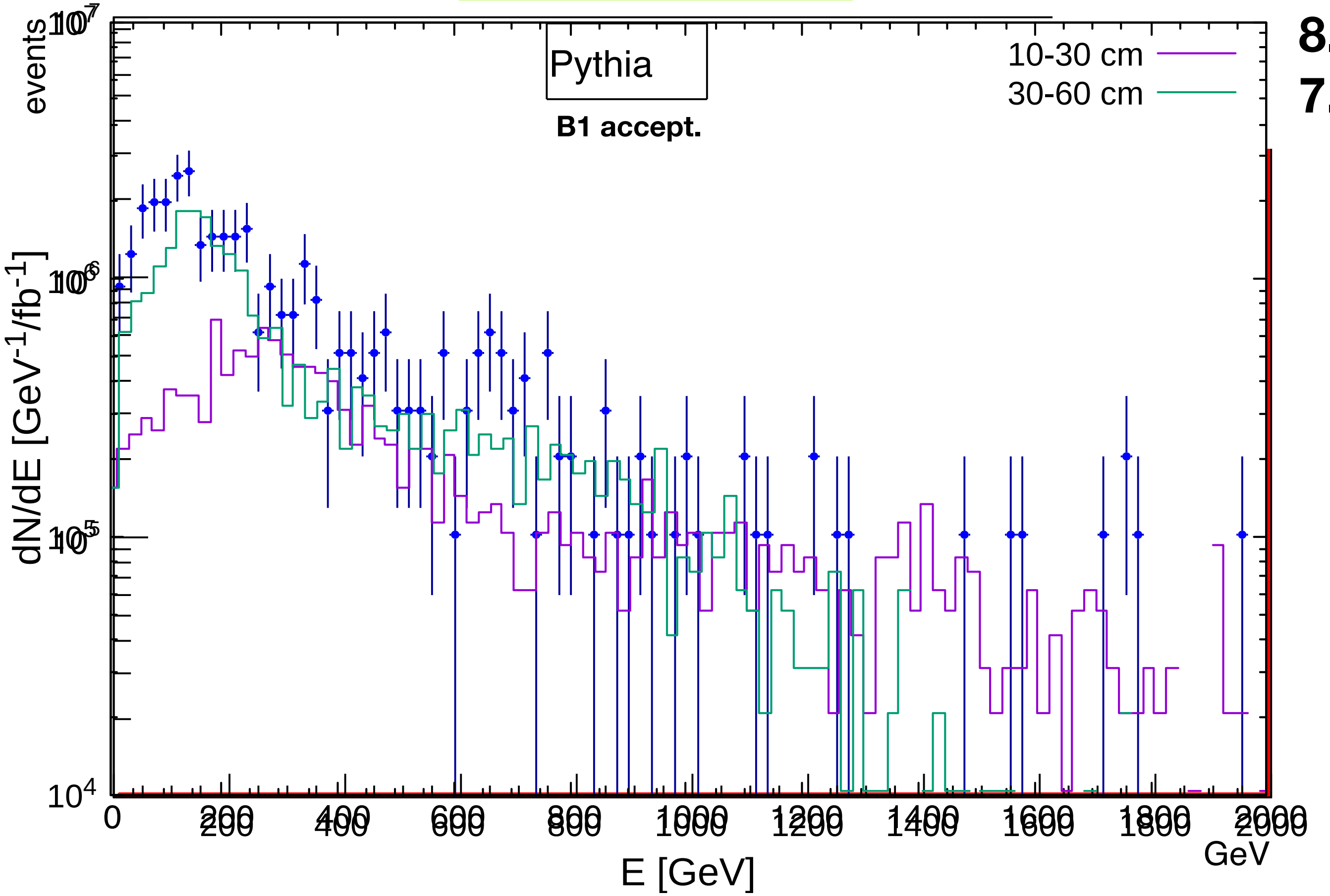
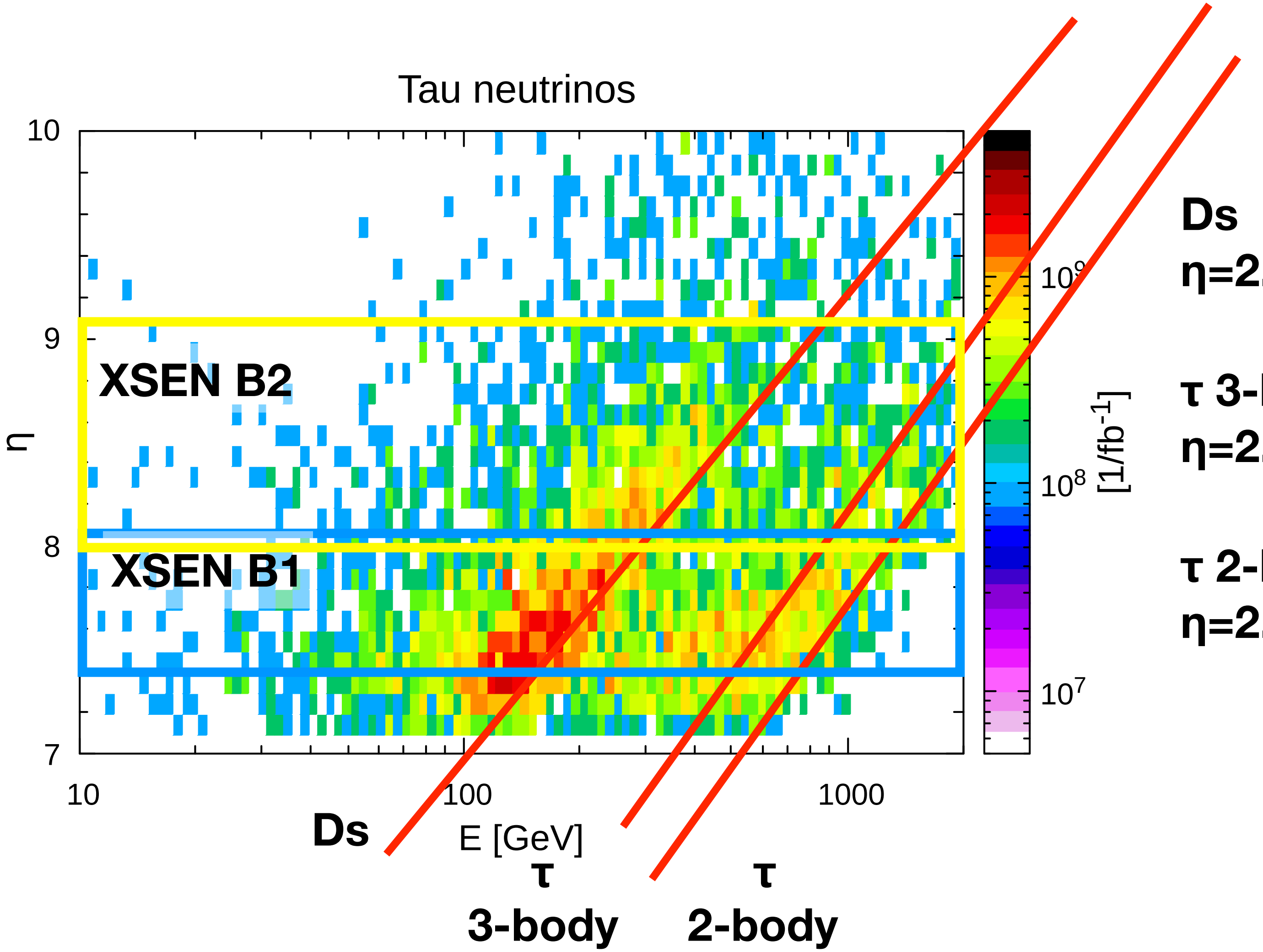
Tau neutrinos



$8.0<\eta_{B2}<9.2$

$7.4<\eta_{B1}<8.1$



Ds

$\eta = 2.3 \log E - \ln(M_D - M_\tau) + \ln 2$

τ 3-body

$\eta = 2.3 \log E - \ln(M_\tau/3) + \ln 2$

τ 2-body

$\eta = 2.3 \log E - \ln(M_\tau/2) + \ln 2$

Summary

- **XSEN is a project for exploiting the huge neutrino flux from LHC collisions, with emphasis on TeV neutrinos and tau flavour**

Beni, N. et al, “Physics Potential of an Experiment using LHC Neutrinos” , J. Phys. G: Nucl. Part. Phys. 46 (2019) 115008

- **the flux of high energy neutrinos in the region 7.4 < η < 9.2, dominantly from charm decays, can be intercepted by a compact (a few tons) detector placed “off-axis” in the cavern of the TI18 decommissioned tunnel. In LHC Run3, the location is suitable for nuclear emulsions, good for tagging taus**

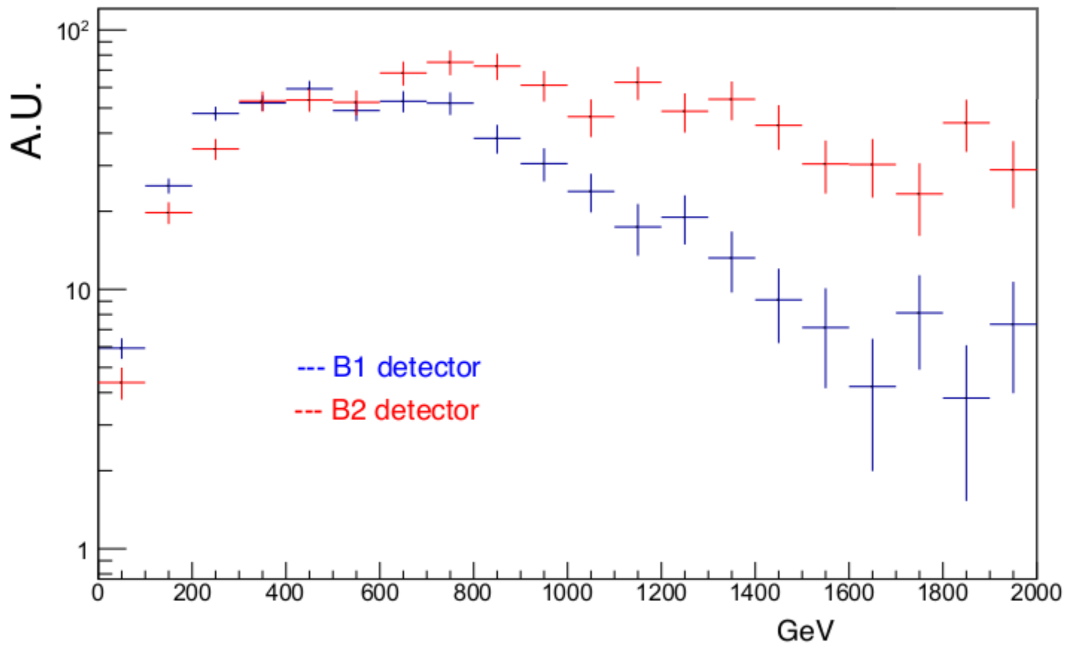
Beni, N et al., Letter of Intent , XSEN: a vN Cross Section Measurement using High Energy Neutrinos from pp collisions at the LHC, CERN-LHCC-2019-014 ; LHCC-I-033

- **complementary to FASER**
- **In LHC Run3 with 150 /fb a <3 ton detector can collect up to 2000 high energy neutrino interactions and up to 100 tau neutrino events, and explore, also by neutrino flavour,**

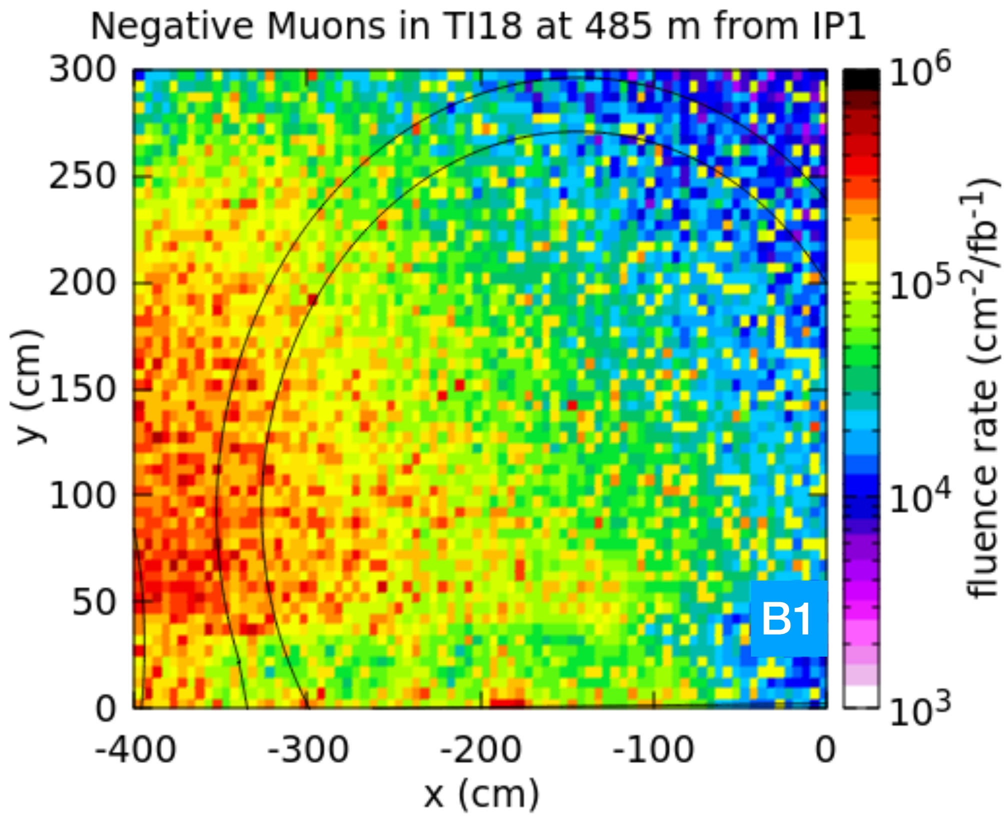
- the pp-> *v* + X , testing very forward charm production

- the *v*N cross section in the 0.5-1.5 TeV region

additional



two independent energy bins



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