SND@LHC

Scattering and neutrino detector at the LHC

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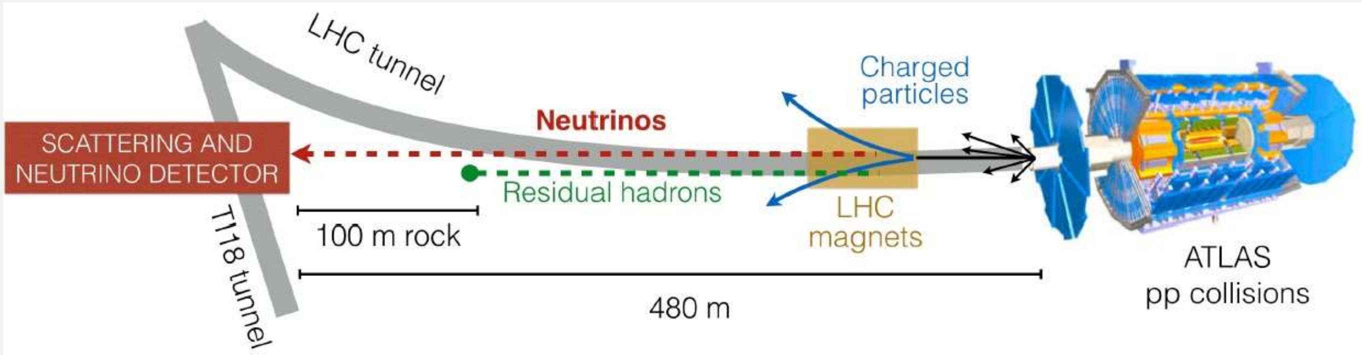
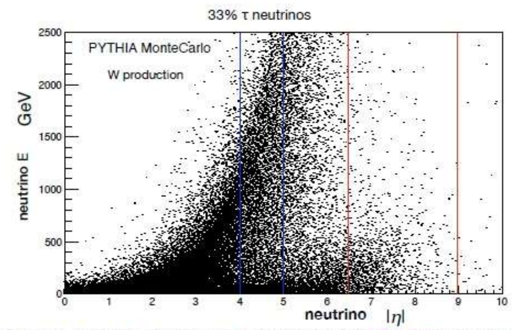


Outline

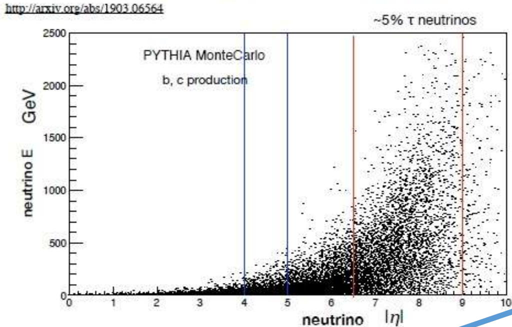
- - Introduction
- - The detector
- - Physics programme
- - Test beam
- - Conclusions

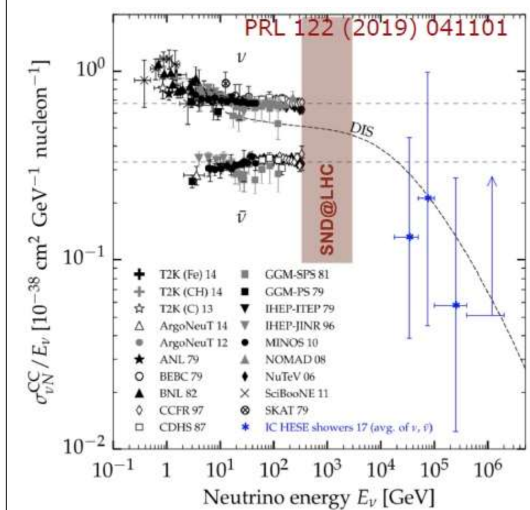
I: Motivation

- Abundant high E 100-2000 GeV ν_e, ν_μ, ν_τ flux from W, c decays at the LHC (lower E ν_μ also from π/K decay) – could fill the gap between accelerator (mostly ν_μ, few ν_e) and astrophysics measurements – also, only 14 ν_τ observed so far
- LHC Run 3, 2022-2024, ~150 fb-1 & O(ton) detector with good tracking and PI can do the job
- ν from W decays a priori more interesting (they could be tagged with leptons detected in ATLAS/CMS) – tests at different distances from IP5 exclude this possibility (η ~ 4.5, θ ~ 22 mrad, max distance from IP ~ 25 m: overwhelming n, μ background) => η ~ 8, θ ~ 0.7 mrad at a distance 480 m from IP1 is chosen for a compact detector
- -> SND@LHC was approved by the CERN Research Board on 17 March 2021

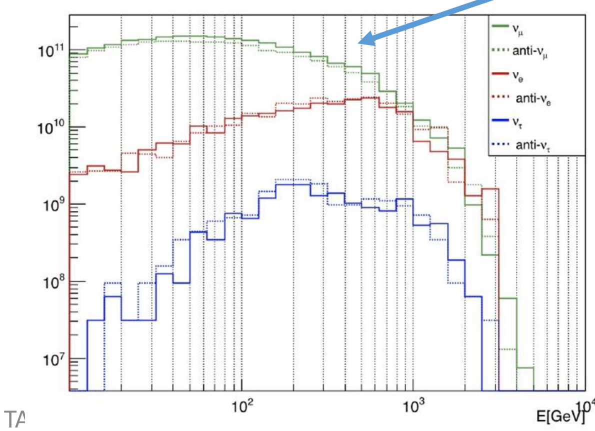


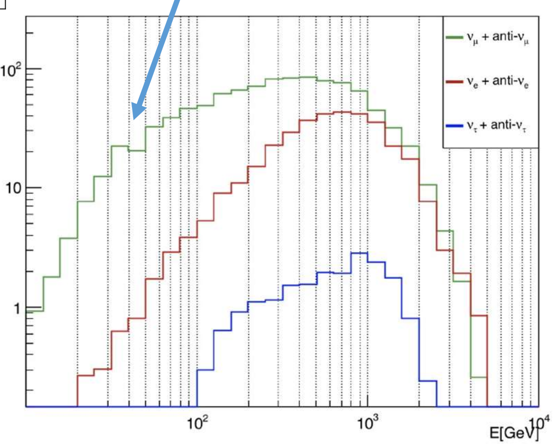
N. Beni et al., Physics Potential of an Experiment using LHC Neutrinos, J. Phys. G 46 (2019) 115008
http://arxiv.org/abs/1903.06564





- Incoming 7.2<η<8.6
- Interacting “

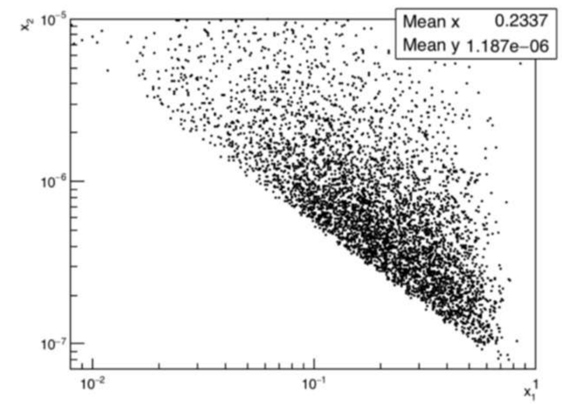


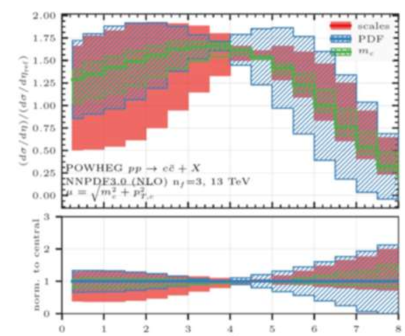


I: Motivation (cont.)

- Study ν interactions (cross-section, LFU, ..) in a new energy domain
- Systematic uncertainty on the cross-section measurement dominated by the uncertainty on the ν flux
- Study the ν source, i.e. using νs as probes, e.g. in some angular region ν_e production dominated by charm decays -> measure charm production in pp collisions in the forward region
- Interest for the charm measurement in pp collision at high η (LHCb up to 4.5 in η)
- Prediction of very high-energy ν produced in cosmic-ray interactions -> experiment also acting as a bridge between accelerator and astroparticle physics

Gluon PDF in an x-region relevant for Future Circular Colliders



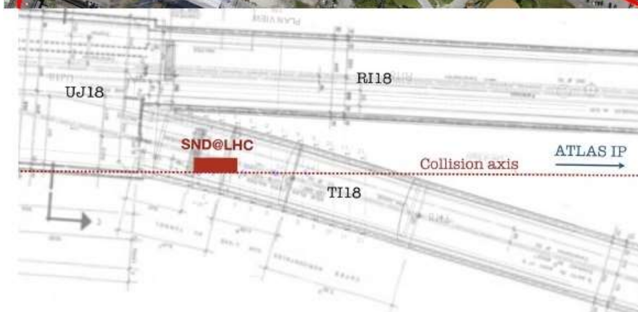


$$R = \frac{d\sigma/d\eta(13\,TeV)}{d\sigma/d\eta_{ref}(7\,TeV)}$$

η_{ref}~4-4.5

I: Location

- TI18 tunnel
  - Former service tunnel connecting SPS to LEP
  - Symmetric wrt TI12 where FASER is located
  - Initially no infrastructed for operating an active detector!
- ~ 480 m from ATLAS interaction point (IP1)
  - Line of sight shielded by ~100 m rock, only μ and thermal n from beam-gas interaction (and ν) survive
  - Charged particles from IP swept away by LHC magnets
- Detector offset wrt the collision axis, both physics-wise (very forward ν dominated by π and K decay) & no excavation necessary (just a concrete base)
  - Angular acceptance $7.2 < \eta < 8.6$



LHC seen from the tunnel (empty)

Concrete base & (empty) electronics racks …

D: Detector concept & layout

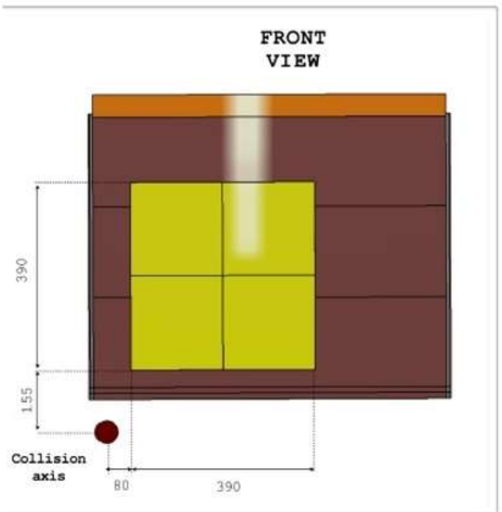
- Angular acceptance: $7.2 < \eta < 8.6$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm^2

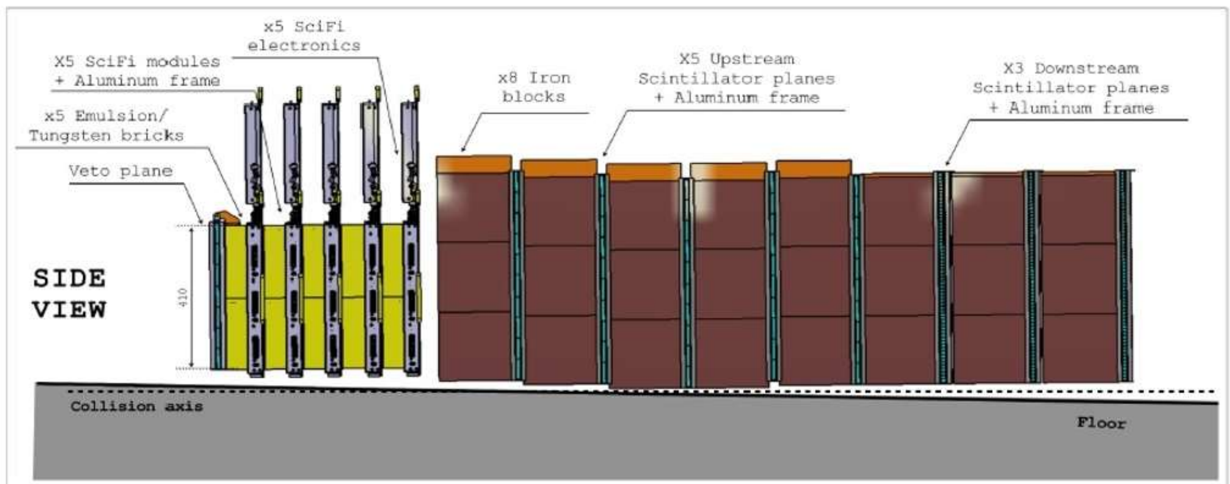
Veto Plane, Target Region (emulsion & tungsten), Muon system/Had Calo

Off axis location

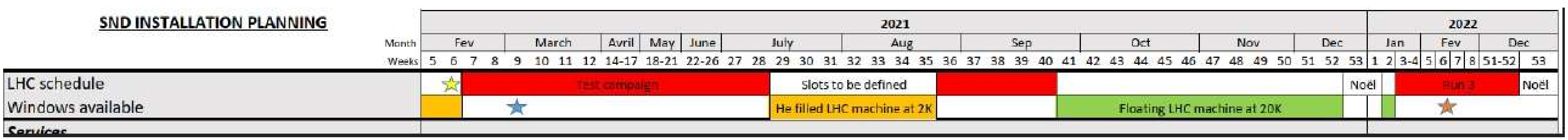
Electromagnetic calorimeter
On average ~40 X_0

Hadronic calorimeter
On average ~11 λ



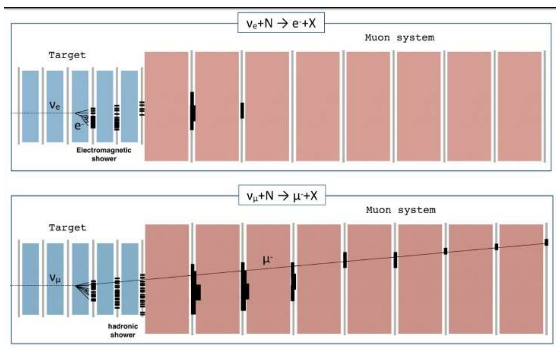


SND INSTALLATION PLANNING

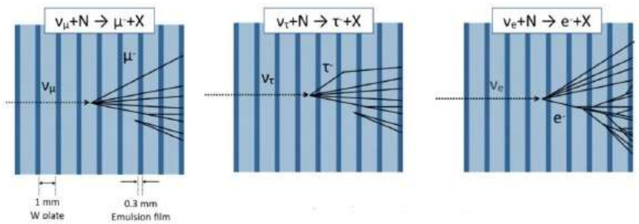


D: Event reconstruction

- 1st: electronic detectors (Veto, Target Tracker and Muon system)
  - Identify ν candidates
  - Identify μ's in final state
  - em showers (SciFi)
  - ν energy (SciFi+Muon)



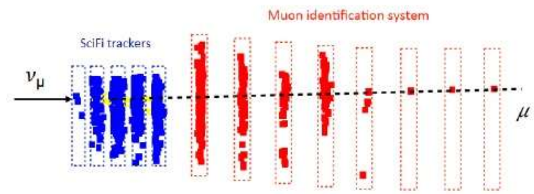
- 2nd: nuclear emulsions (event reconstruction in emulsion target)
  - Identify em showers
  - ν vertex reconstruction and secondary search
  - Match with candidates from electronic detectors (time stamp)



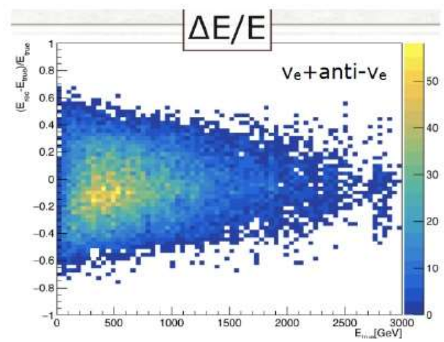
D: Muon identification, energy resolution

- ν_μ CC interactions identified by muons, last 3 μ stations equipped with 1 cm wide scintillator bars (others with 6 cm wide ones)
- μ-ID at ν vertex crucial to identify charmed hadron production, background to ν_τ detection

	% evts CC-DIS	% evts NC-DIS
0μ	31.1	99.6
1μ	67.6	0.27
2μ	1.1	0.06



- Sampling calorimeter (SciFi + μ filter)
- Average resolution on hadron shower energy: 22% (simple counting $E_h^{rec} = A + B\ N_{SciFi} + C\ N_{\mu filt}$)
- ML algorithms being developed to improve resolution
- Much better em energy resolution



Ph: Main physics goals

$7.2 < \eta < 8.6,\ 0.4 < \vartheta < 1.5$ mrad

Measurement	Uncertainty Stat.	Sys.
$pp \to \nu_e X$ cross-section	5%	15%
Charmed hadron yield	5%	35%
ν_e/ν_τ ratio for LFU test	30%	22%
ν_e/ν_μ ratio for LFU test	10%	10%
NC/CC ratio	5%	10%

- Expectations in 150 fb^{-1} (50/50 upward/downward crossing angle)

Flavour	CC neutrino interactions ⟨E⟩ [GeV]	CC Yield	NC neutrino interactions ⟨E⟩ [GeV]	NC Yield
ν_μ	452	606	480	182
$\bar{\nu}_\mu$	485	248	480	93
ν_e	760	182	720	54
$\bar{\nu}_e$	680	97	720	35
TOT		1133		364

~ 20 ν_τ CC interactions expected

Upward beam crossing angle

Flavour	Neutrinos in acceptance ⟨E⟩ (GeV)	Yield	CC neutrino interactions ⟨E⟩ (GeV)	Yield	NC neutrino interactions ⟨E⟩ (GeV)	Yield
ν_μ	145	2.1×10^{12}	450	730	480	220
$\bar{\nu}_\mu$	145	1.8×10^{12}	485	290	480	110
ν_e	395	2.6×10^{11}	760	235	720	70
$\bar{\nu}_e$	405	2.8×10^{11}	680	120	720	44
ν_τ	415	1.5×10^{10}	740	14	740	4
$\bar{\nu}_\tau$	380	1.7×10^{10}	740	6	740	2
TOT		4.5×10^{12}		1395		450

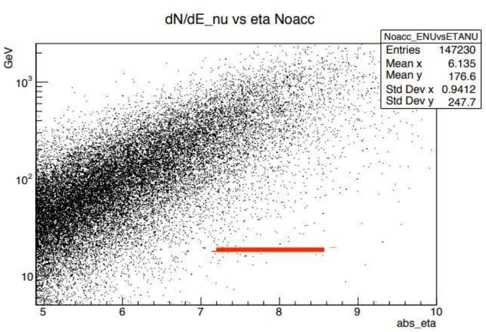
Downward beam crossing angle (35% decrease)

Flavour	CC neutrino interactions ⟨E⟩ [GeV]	Yield	NC neutrino interactions ⟨E⟩ [GeV]	Yield
ν_μ		483		145
$\bar{\nu}_\mu$		206		77
ν_e		130		38
$\bar{\nu}_e$		74		27
TOT		893		287

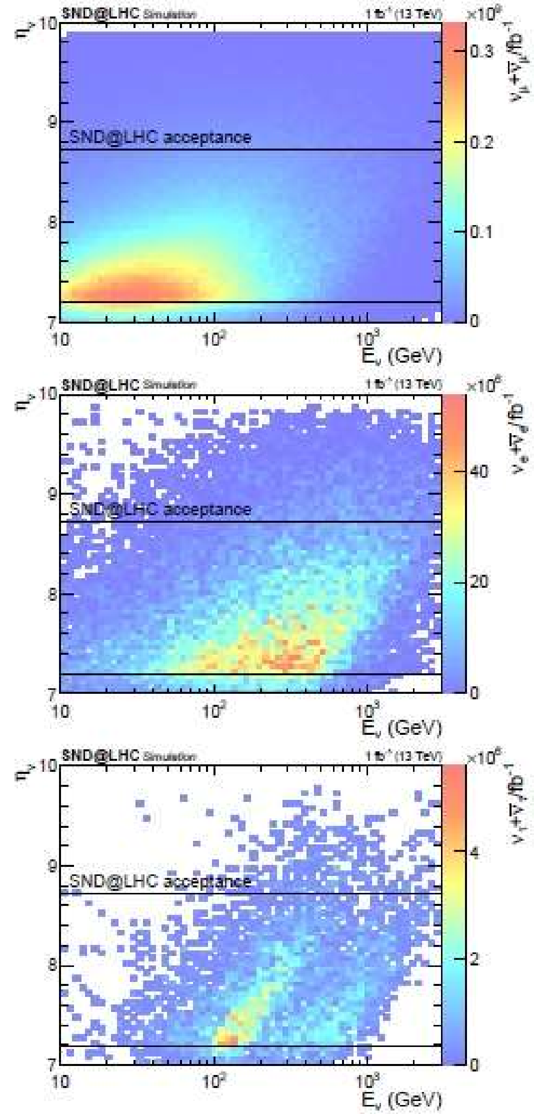
Neutrino interactions in the acceptance estimated with DPMJET3/FLUKA for 150 fb-1

Ph: Flux vs η & Eν

- ν_e , ν_τ mainly from decay of charmed hadrons
  - 10% ν_e from K (<200 GeV), 3% from beauty, interacting within acceptance
- measure charm production by observing ν_e and antiν_e
- Soft ν_μ component from π and K decays



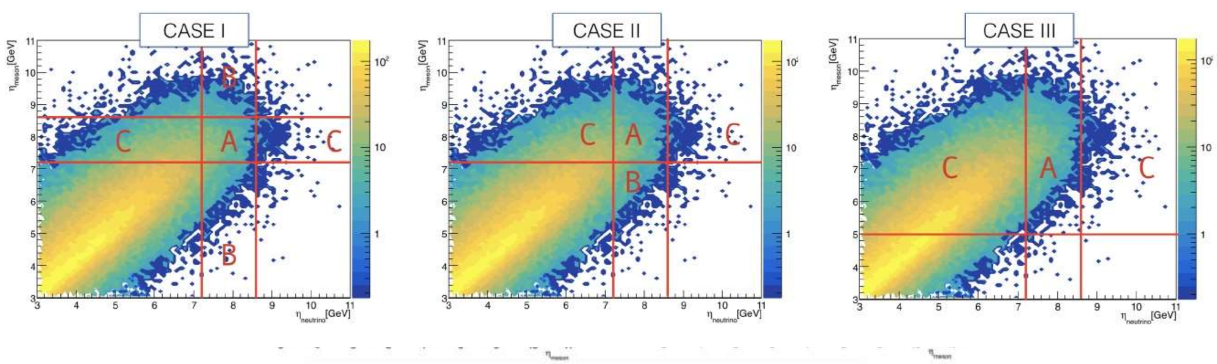
ν flux from c, b decays simulated with PYTHIA8



DPMJET /FLUKA π/K included tunnel & Machine simulated

Ph: Charm production measurement

- ~(100)180 (antiν_e) ν_e interactions expected in 150 fb-1
  - Measure the energy spectrum of ν_e+ antiν_e
  - Unfold energy resolution effects to get the reconstructed ν_e+ antiν_e energy spectrum
  - Apply deconvolution of the (SM predicted/assumed) ν/antiν cross-section to get incoming neutrino flux → ν_e X
  - From ν_e back to charm, to estimate the charm production yield
- ~5% (stat), ~35% (syst.: K subtraction (mainly E<200GeV), unfolding and ν_e-charm hadron correlation)



Ph: Cross section ratios - LFU

- ν_τ mainly from $D_s \rightarrow \tau\nu_\tau$ (8% from beauty)
  - νe from D0, D, Ds and Λc
  - ν_e/ν_τ only depends on charm hadronization and decay branching fractions

$$R_{13} = \frac{N_{\nu_e+\overline{\nu}_e}}{N_{\nu_\tau+\overline{\nu}_\tau}} = \frac{\sum_i \tilde{f}_{c_i} \tilde{Br}(c_i \rightarrow \nu_e)}{\tilde{f}_{D_s} \tilde{Br}(D_s \rightarrow \nu_\tau)}$$

  - Uncertainties due to charm quark production cancel out
  - ν_e/ν_τ : sensitive to ν-nucleon interaction cross section ratio (22% syst.)
  - test of lepton universality in neutrino interactions (30% stat. due to ν_τ sample size)
- ν_e/ν_μ branching fractions practically equal
  - Large contamination of ν_μ from π and K, stable above 600 GeV (15% accuracy)
  - $\omega_{\pi/K}$ - contamination

$$R_{12} = \frac{N_{\nu_e+\overline{\nu}_e}}{N_{\nu_\mu+\overline{\nu}_\mu}} = \frac{1}{1+\omega_{\pi/k}}$$

Ph: NC/CC

- Lepton identification for three flavours allows to distinguish CC from NC interactions
- If ν and antiν fluxes are equal:

$$P = \frac{\sigma^{\nu}_{NC} + \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} + \sigma^{\bar{\nu}}_{CC}}$$

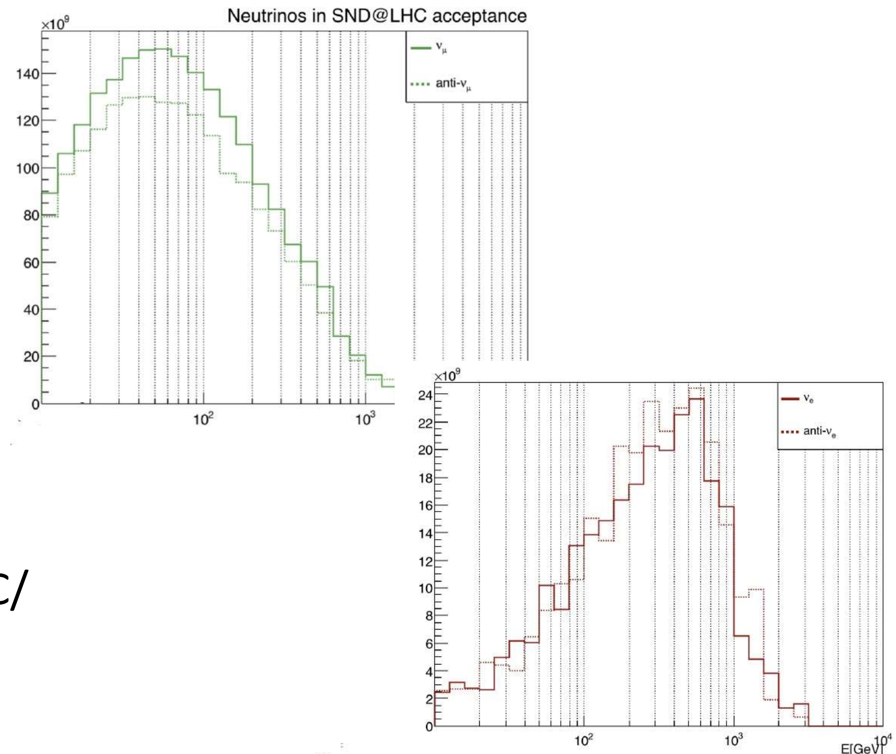
(~10% syst. ν/antiν asym., μ ID, n induced events, CC/ /NC migration; ~5% stat. nb of NC interactions)

- In case of DIS:

$$P = \frac{1}{2}\left\{1 - 2\sin^2\theta_W + \frac{20}{9}\sin^4\theta_W - \lambda(1 - 2\sin^2\theta_W)\sin^2\theta_W\right\}$$

For tungsten, λ=0.04

- Use this as a control measurement



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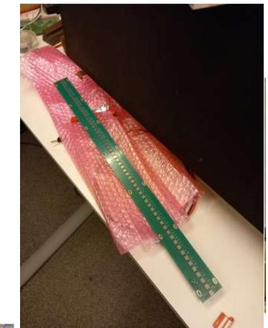
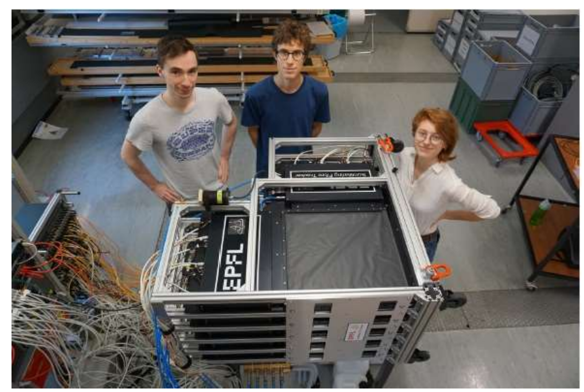
TB: Detector assembly

- Emulsion box prototype assembled, being tested
- Veto – Fully assembled
- UpStream muon/HCAL
  - Fully assembled
  - Currently at test beam (H8) for E calibration with mock up Fe target
- DownStream muon
  - 2 out of 3 planes assembled
  - Currently at test beam (H8)
- SciFi tracker/ECAL fully assembled
  - Tested with CRs, just moved to test beam (H6)





D: Detector in H8

- Test beam with HCAL/Muon (US complete &DS 1/2 out of 3 stations) system + 30 cm Fe, to simulate a hadron shower starting in the middle of the target, at the CERN SPS (H8)
- Data taking with πs (180, 140, 100 GeV) beginning of Sep., repeated these days at 300, 250 GeV
- Data (being analyzed) extremely important to calibrate MC
- The apparatus will later be moved to H6 to be tested with μs

Conclusions

- SND@LHC was approved in March 2021
- Compact detector for neutrino studies to be ready for Run 2 data taking (Feb 2022)
- Expect ~ 1500 neutrino events for 150 fb-1
- Area being equipped (from void): on schedule
- Detector construction is proceeding on schedule, installation in Nov-Dec
- Test beam of US and DS muon detectors with pions ongoing, later commissioning with muons

Thank you