Status of SND@LHC
THE SCATTERING AND NEUTRINO DETECTOR AT THE LHC

Prof S. Kuleshov (Universidad Andrés Bello/ SAPHIR Millennium Institute)

On behalf of the SND@LHC Collaboration

8th International Conference on High Energy Physics in the LHC Era
Jan. 9-13, 2023. Universidad Técnica Federico Santa María, Valparaíso, Chile
Current neutrino physics at LHC experiments

Generally referred as “forward physics”, referring to regions of the detector(s) which are close to the beam axis, at high pseudorapidity $\eta$

$$\eta = \text{arctanh} \left( \frac{p_L}{|p|} \right)$$
SND@LHC & FASER

Detector

Length: 7 m
Aperture: 20 cm
Length of decay volume: 1.5 m

Length: 2.6 m
Aperture 390x390 mm²
OVERVIEW

‣ The SND@LHC experiment
‣ Detector installation
‣ Data taking in Run3

Physics Program (Backup slides.)
‣ Neutrino physics program
‣ QCD measurements
‣ Search for feebly interacting particles

Advanced SND@LHC (Backup)

SND@LHC Technical Proposal

Approved by the Research Board on March 2021

https://snd-lhc.web.cern.ch/
MOTIVATION

Neutrino physics at the LHC
- Klaus Winter, 1990, observing tau neutrinos at the LHC
- F. Vannucci, 1993, neutrino physics at the LHC

PRL 122 (2019) 041101

CERN is unique in providing energetic $\nu$ (from LHC) and measure $pp \rightarrow \nu X$ in an unexplored domain

Physics potential of an experiment using LHC neutrinos

Further studies on the physics potential of an experiment using LHC neutrinos
Charged particles deflected by LHC magnets
- Shielding from the IP provided by 100 m rock
- Angular acceptance: $7.2 < \eta < 8.4$
- First phase: operation in Run 3 to collect 150 fb$^{-1}$

- About 480 m away from the ATLAS IP
- Tunnel TI18: former service tunnel connecting SPS to LEP
- Symmetric to TI12 tunnel where the FASER is located
NEUTRINO EXPECTATIONS

- Integrated luminosity: 290 fb$^{-1}$
- Upward/downward crossing angle: 0.43/0.57

- Neutrino production in LHC pp collisions performed with DPMJET3 embedded in FLUKA
- Particle propagation towards the detector through FLUKA model of LHC accelerator

<table>
<thead>
<tr>
<th>Flavour</th>
<th>Neutrinos in acceptance</th>
<th>CC neutrino interactions</th>
<th>NC neutrino interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_\mu$</td>
<td>120</td>
<td>450</td>
<td>480</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$</td>
<td>125</td>
<td>480</td>
<td>480</td>
</tr>
<tr>
<td>$\nu_e$</td>
<td>300</td>
<td>760</td>
<td>720</td>
</tr>
<tr>
<td>$\bar{\nu}_e$</td>
<td>230</td>
<td>680</td>
<td>720</td>
</tr>
<tr>
<td>$\nu_\tau$</td>
<td>400</td>
<td>740</td>
<td>740</td>
</tr>
<tr>
<td>$\bar{\nu}_\tau$</td>
<td>380</td>
<td>740</td>
<td>740</td>
</tr>
<tr>
<td>TOT</td>
<td>$7.3 \times 10^{12}$</td>
<td>1930</td>
<td>625</td>
</tr>
</tbody>
</table>
Experiment concept

Hybrid detector optimised for the identification of all three neutrino flavours.

**VETO PLANE:**
tag penetrating muons

**NEUTRINO TARGET & VERTEX DETECTOR:**
- Emulsion cloud chambers (60 emulsion films, 300µm thick, interleaved by 1mm thick tungsten plates)

**E.M. CAL**
- 250µm Scintillating fibres for timing information and e.m. energy measurement

**HADRONIC CALO:**
iron walls interleaved with plastic scintillator planes for a total of about 11 λ

**MUON IDENTIFICATION SYSTEM:**
3 most downstream plastic scintillator stations based on fine-grained bars, meant for the muon identification and tracking
THE DETECTOR LAYOUT

- Angular acceptance: $7.2 < \eta < 8.4$
- Target material: Tungsten
- Target mass: 830 kg
- Surface: 390x390 mm$^2$

Off axis location

Electromagnetic calorimeter
~40 $X_0$

Hadronic calorimeter
~10 $\lambda$

Front view

SIDE VIEW

Collision axis

5x Emulsion/Tungsten bricks
2x Veto planes
5x SciFi planes
8x Iron blocks
5x Upstream Scintillator planes
3x Downstream Scintillator planes
Collision axis
SND@LHC in the TI18 cavern

Side view

Top view
UPSTREAM VETO DETECTOR

- **Goal**: charged background particles fixation
- **Located upstream of the neutrino target**
NEUTRINO TARGET AND VERTEX DETECTOR

- Goals:
  - detecting neutrino interactions (all flavours); energy measurement
  - search for FIPs
EMULSION TARGET

Target assembled according to the Emulsion Cloud Chamber (ECC) technique:
Tungsten layers (1mm-thick) alternated to nuclear emulsion films

The AgBr crystals, with a diameter of 0.2\(\mu\)m, are sensitive to minimum ionizing particles (MIP).
A chemical process, known as development, enhances latent images inducing the growth of silver clusters (grains) with a diameter of 0.6 \(\mu\)m, visible by an optical microscope.

Sub-micrometric position resolution
EMULSION SCANNING AND ANALYSIS

Optical system for the scanning of emulsion films @Napoli Laboratory

Reconstructed cosmic-ray tracks in the SND@LHC wall used in the commissioning
- Bologna: 1 system upgraded, software installation to be performed
- Lebedev: 1 system upgraded, ready to scan
- Napoli: 1 system upgraded, ready to scan
- Zurich: 1 system upgraded, ready to scan
- CERN: 1 system, upgraded, ready to scan NEW
General layout of the target region. SciFi modules.
SciFi for SND@LHC Fiber module elements.

The fiber type is SCSF-78MJ, produced by Kuraray, Japan. It has a diameter of 0.25 mm and is made of polystyrene core with added dye and wavelength shifter, and two claddings with lower refraction index.

$10^3$ photons/MeV, decay time=2.8 nS,

Emission spectra from 400 nm to 600 nm with peak near 450 nm

The active elements of the detector are scintillating fiber mats composed of six fiber layers, with dimensions width × length × height: 130.65 × 800.0 × 1.4 mm.

arXiv:1710.08432v1
SciFi for SND@LHC

Scintillating fibers read out by SiPMs
- 5 stations interleaved with emulsion targets
- X and Y coordinate measurements in each station

Final detector installation in TI18

Single SciFi module with X and Y planes

1536 readout channels per side
- 250 μm pitch, with gaps every 64 channels
- Read out by 3 DAQ boards, 8 TOFPET2 ASICs each
MUON SYSTEM AND HADRONIC CALORIMETER

Goals:
- muon tracking and identification
- measurement of the energy of the hadronic jet
Summary of the experiment main milestones

- Letter of Intent: Aug 27th, 2020
- Technical Proposal: Jan 22nd, 2021
- Approval by CERN RB: Mar 2021
- Experimental area & infrastructure: Jun 28 – end Aug
- Detector construction completion: Oct 13
- Detector surface commissioning: Sep - Oct
- Test beams: Sep 1-5, Oct 1-6
- Start of detector installation in TI18: Nov 1
- Turn on and global commissioning: Dec 7
- Detector commissioning and debugging: Jan-Feb
- Installation of the neutron shield: Mar 15
- Installation of the first emulsion films: Apr 7
- First data from “splash”/collision: Apr, May
- First 13.6 TeV collisions: July 5th

SND@LHC Technical Proposal
DETECTOR INSTALLATION IN TI18

- Installation in TI18 started on November 1\(^{st}\) 2021
- Electronic detector installation completed on December 3\(^{rd}\) 2021
- Installation of the neutron shield completed on March 15\(^{th}\) 2022
- Installation of the emulsion detector on April 7\(^{th}\) 2022

Chillean team contribution.
EMULSION TARGET ASSEMBLY AND INSTALLATION

- Full target system equipped with emulsion films installed on July 26th
- Total mass: 830 kg
- Number of emulsion films: 1200
DATA TAKING IN RUN3

Cosmic ray
(March 5th 2022)

15 tracks selected randomly in 1x1 cm2 - 57 emulsion films
RUN0 emulsion target: April 7th - July 26th (0.51 fb⁻¹)

Muon from pp collisions @13.6 TeV
(July 6th 2022)
Integrated luminosity in Run 3 for the different emulsion batches

Delivered: 41.3 fb\(^{-1}\)
Recorded: 39.8 fb\(^{-1}\) (96%)
Plan for the 2023 run

2023 – Q1

2023 – Q2

2023 – Q3

2023 – Q4

- 14 m² emulsion films will be produced by Slavich, ~10 m² ready by mid March for the first target (see Tatiana’s talk)
- The other part will be produced in Nagoya (see Komatsu-san’s talk)
10.9 fb$^{-1}$ with detector fully operational

Good proportionality between our event rate and ATLAS measured luminosity except in the beginning of the run (start of the fill, backward events, ….)
EVENT RATE

Event rate for one run
Start: October 4\textsuperscript{th} 2022, 18:12:22
End: October 5\textsuperscript{th} 2022, 09:52:21
SND@LHC observed bunch structure overlaid with the LHC filling scheme with phase shift adjusted

phase shift B1, B2: 1456,129 for run 4809 fill nr 8146

Colour coding:
blue Beam1,
red IP1 xing,
cyan Beam2,
yellow IP2 xing

Most of the events from interactions in IP1

Phase shift of B2 relative to B1 of 129 clock (25ns) cycles is also a measurement of the distance of SND@LHC from IP1:

\[2 \times \frac{482 \, m}{0.3 \, \frac{m}{ns} \times 25 \, ns} = 128.6\]
Use bunch structure to study event features: the track direction

**Track Velocity**

- **Blue:** beam 1
- **Cyan:** beam 2

**Beam 1**

**Beam 2**

**Track Velocity**
Performance: Veto inefficiency due to deadtime

SciFi tracks at the rate of \( \sim 500 \text{ Hz} \)

Measured inefficiency of \( 10^{-4} \) corresponds to a deadtime of about 200 ns

\[
\eta = 1 - \varepsilon = 10^{-4}
\]
Track reconstruction also with emulsion data

muon track recorded on July 6\textsuperscript{th} from pp @13.6 TeV

Track rates in emulsion compatible with electronic detectors

RUN0 from April 7\textsuperscript{th} to July 26\textsuperscript{th} (0.51 fb\textsuperscript{-1})
First look at the emulsion data!

0.5 fb\(^{-1}\) integrated from April 7\(^{th}\) to July 26\(^{th}\)

Measured track density in emulsion \(\sim 9000/cm^2\)

With SciFi, average track density \(\sim 8000/cm^2\)

Beam peak at very small angles as expected

\(\sim 9000/cm^2\) in 0.5 fb\(^{-1}\) \(\rightarrow\) \(\sim 4 \times 10^{5}/cm^2\) in 20 fb\(^{-1}\)!
EMULSION / SCIFI COMPARISON

SciFi

Measured rates on BRICK1 surface
1.4x10^4 fb/cm²

EMULSIONS

Measured rates in BRICK1
1.5 x10^4 fb/cm²

PEAK1 Mean 3.4 mrad
Sigma 1.6 mrad

PEAK2 Mean 7.9 mrad
Sigma 3.1 mrad

Δtx = 4.5 mrad

PEAK1 Mean 5.2 mrad
Sigma 2.5 mrad

PEAK2 Mean 11.9 mrad
Sigma 3.4 mrad

Δtx = 6.7 mrad
DATA TAKING IN RUN3

Reconstructed tracks in the first runs @13.6 TeV
Direction compatible with coming from pp collisions at IP1
EVENT RECONSTRUCTION

- **FIRST PHASE: electronic detectors**
  - Event reconstruction based on Veto, Target Tracker and Muon system
  - Identify neutrino candidates
  - Identify muons in the final state
  - Reconstruction of electromagnetic showers (SciFi)
  - Measure neutrino energy (SciFi+Muon)

- **SECOND PHASE: nuclear emulsions**
  - Event reconstruction in the emulsion target
    - Identify e.m. showers
    - Neutrino vertex reconstruction and 2ry search
    - Match with candidates from electronic detectors (time stamp)
    - Complement target tracker for e.m. energy measurement
Multi-track events

- Run 4964: \( \int L dt = 0.31 fb^{-1}, \sigma_{\text{inelastic}} = 80 mb \), 2448 bunch crossings of 3564, \( N_{\text{collisions}} = 25 \times 10^{12}, T = 26 \times 10^3 s, N_{\text{xings}} = 0.72 \times 10^{12} \)
- Efficiency corrected average over this run: 300 tracks/s
- Single muon per bunch crossing: \( \mu = 1.1 \times 10^{-5} \)
- Probability for k-track event from pile-up: \( \frac{\mu^k e^{-\mu}}{k!} \)
  - 2 \( \mu \) per bunch xing: \( p_2 = \frac{1}{2} \mu^2 \)
  - 3 \( \mu \) per bunch xing: \( p_3 = \frac{1}{6} \mu^3 \)
  - Expect \( N_{2 \text{track}} = 43 \), observed 224
- Additional rate could be due to trident process, muon pair production in rock, concrete, tungsten.
- Hypothesis supported by 3-track events
Three-track events

Expect: $N_{3\,\text{track}} = 2 \times 10^{-4}$

Observed: $> 4$
The LHCC commends SND for the rapid installation and commissioning of the detector which has been ready to collect pp data for physics in complete configuration since the end of July.

The LHCC congratulates SND for the efficient solution of the film procurement, which is now fully guaranteed by Nagoya University for run 3. The LHCC also appreciates the special effort to procure the needed films for the unexpected extension of the pp running time.

The LHCC congratulates SND, FASERnu and CERN on the well-coordinated development and use of the Emulsion Facility (EF) which now also includes the new scan station.

The LHCC recommends for the next meeting the definition of the process allowing the timely replacement of films during Run 3 for SND and the other experiments and the sharing of the EF with the other users.

The LHCC endorses the energy calibration test beam foreseen in spring 2023 and strongly supports the request for two weeks of beam time.
Concluding remarks:

- Successful operation of the detector over the first Run 3 year
- A third (unforeseen) emulsion target added this year to cope with the extended pp physics run
- Three fully instrumented targets have recorded about 41 fb$^{-1}$
- Smooth operation with a few hiccups fixed during short accesses
- Data alignment with bunch structures has allowed studying the background component in the reconstructed tracks
- Good correlation between beam1/2 and forward/backward direction
- Muons track reconstruction with electronic detectors working well
- Measured good agreement between emulsion and SciFi tracks for the muon rates
- Multi-track event rates hinting for the presence of additional physics processes on top of the pileup

A big thank to CERN for the excellent operation of the LHC beam and for the refurbishment of the emulsion facility!
New era of collider neutrinos started!

https://cerncourier.com/a/collider-neutrinos-on-the-horizon/

Stay tuned! Data taking just started!
LHC Run3: 2022-2025
BACKUP SLIDES
WITH MORE DETAILED INFORMATION
KEY FEATURES

• Muon identification

- $\nu_\mu$ CC interactions identified thanks to the identification of the muon produced in the interaction
- Muon ID at the neutrino vertex crucial to identify charmed hadron production, background to $\nu_\tau$ detection

• Energy measurement

- The detector acts as a non-homogeneous sampling calorimeter

- Combing information from SciFi (target region) and Scintillator bars (Muon System)
- Average resolution on $\nu_e$ energy: 22%

- Performance of SciFi tracker as sampling calorimeter, using a CNN
- Electron energy resolution

<table>
<thead>
<tr>
<th>% evts</th>
<th>% evts</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC-DIS</td>
<td>NC-DIS</td>
</tr>
<tr>
<td>0µ</td>
<td>31.1</td>
</tr>
<tr>
<td>1µ</td>
<td>67.6</td>
</tr>
<tr>
<td>2µ</td>
<td>1.1</td>
</tr>
<tr>
<td>99.6</td>
<td>0.27</td>
</tr>
<tr>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>
1. Measurement of the $pp \rightarrow v_e X$ cross-section
2. Heavy flavour production in pp collisions
3. Lepton flavour universality in neutrino interactions
4. Measurement of the NC/CC ratio
1. MEASUREMENT OF $pp \rightarrow \nu eX$ CROSS-SECTION

- Simulation predicts that 90% $\nu_e + \text{anti-}\nu_e$ come from the decay of charmed hadrons
- Electron neutrinos can be used as a probe of the production of charm in the relevant pseudo-rapidity range after unfolding the instrumental effects
- Reconstructed spectrum of $\nu_e + \text{anti-}\nu_e$ flux in SND@LHC acceptance

2. CHARMED HADRON PRODUCTION

- Correlation between pseudo-rapidity of the electron (anti-)neutrino and the parent charmed hadron

CASE I: $7.2 < \eta_{\text{meson}} < 8.6$
QCD MEASUREMENTS

The dominant partonic process for associated charm production at the LHC is gluon-gluon scattering.

Average lowest momentum fraction: $10^{-6}$

Correlation between $x_1$ and $x_2$ for events in the SND@LHC acceptance

Extraction of gluon PDF in very small $x$-region relevant for Future Circular Colliders

Ratio between the cross-section measurements at different energies and pseudo-rapidities

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

$\eta_{ref} = 4.5$

Reduction of scale uncertainties
Constraint the PDF with data
3. LEPTON FLAVOUR UNIVERSALITY TEST

The identification of three neutrino flavours in the SND@LHC detector offers a unique possibility to test the Lepton Flavor Universality (LFU) sensitive to $\nu$-nucleon interaction cross-section ratio of two neutrino species.

- Sensitive to $\nu$-nucleon interaction cross-section ratio of two neutrino species

\[ R_{13} = \frac{N_{\nu_e + \bar{\nu}_e}}{N_{\nu_e + \bar{\nu}_e}} = \frac{\sum_i \bar{f}_c i B(r(c_i \rightarrow \nu_e))}{\bar{f}_d B(r(D_s \rightarrow \nu_\tau))}, \]

\[ R_{12} = \frac{N_{\nu_e + \bar{\nu}_e}}{N_{\nu_\mu + \bar{\nu}_\mu}} = \frac{1}{1 + \omega_{\pi/k}}, \]

The measurement of the $\nu_e/\nu_\mu$ ratio can be used as a test of the LFU for $E>600$ GeV.
4. MEASUREMENT OF NC/CC RATIO

- Lepton identification for the three different flavors allows to distinguish CC to NC interaction at SND@LHC

- If differential neutrino and anti-neutrino fluxes are equal, the NC/CC ratio can be written as

$$P = \frac{\sum_i \sigma_{\nu_i}^{NC} + \sigma_{\bar{\nu}_i}^{NC}}{\sum_i \sigma_{\nu_i}^{CC} + \sigma_{\bar{\nu}_i}^{CC}}$$

- In case of DIS, $P$ can be written as

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

For a Tungsten target $\lambda = 0.04$

- $P$ measurement used as an internal consistency check

Rept.Prog.Phys. 79 (2016) 12, 124201
### Summary of SND@LHC performances

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Uncertainty</th>
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<tbody>
<tr>
<td>$pp \rightarrow \nu_e X$ cross-section</td>
<td>5%</td>
</tr>
<tr>
<td>Charmed hadron yield</td>
<td>5%</td>
</tr>
<tr>
<td>$\nu_e/\nu_\tau$ ratio for LFU test</td>
<td>30%</td>
</tr>
<tr>
<td>$\nu_e/\nu_\mu$ ratio for LFU test</td>
<td>10%</td>
</tr>
<tr>
<td>Measurement of NC/CC ratio</td>
<td>5%</td>
</tr>
</tbody>
</table>
FLEEBLY INTERACTING PARTICLES

- SND@LHC experiment can explore a large variety of Beyond Standard Model (BSM) scenarios describing Hidden Sector

1. Scattering

**Production**: scalar $\chi$ particle coupled to the Standard Model via a leptophobic portal

**Detection**: $\chi$ elastic/inelastic scattering off nucleons of the target

![Diagram of scattering process]

2. Decay of dark scalars, HNLs, dark photons

**Production**: dark scalars produced in the decay of B mesons, HLN's in the decay of B and D mesons, dark photons via leptophobic mediator

**Detection**: Decays in a pair of charged tracks or monophotons
UPGRADE FOR HL-LHC

- Upgrade of the detector in view of an extended run during Run 4:
- Two off-axis forward detectors:
  - **AdvanceSND-Near**: $4<\eta<5$
    - Overlap with LHCb pseudo-rapidity coverage
    - Reduction of systematic uncertainties
    - Provide normalization for neutrino physics studies
    - Neutrino cross-section measurements
  - **AdvancedSND-Far**: $7.2<\eta<8.4$
    - Overlap Acceptance similar to SND@LHC
    - Charm production measurements
    - Lepton flavour universality

[Diagram of HardQCD: $e\bar{e} + b\bar{b}$]
Upgrade of SND@LHC in view of an extended run during Run 4:
- Extension of the physics case
- New technologies and detector layout
- Two detectors
  - AdvSND-Far \((7.2 < \eta < 8.4)\)
    Possible locations: TI18, Future Forward Facility
  - AdvSND-Near \((4 < \eta < 5)\)
    Possible locations: existing caverns close to IP
DETECTOR COMMISSIONING ON SURFACE

- Full assembly of the detector at H6 in the North Area
- Target on a 2.5 degree slope to simulate the TI18 floor inclination
- Successful mechanical test of all subsystems
- Data taking with muon beam

Sept 2021
TEST BEAM WITH MUON SYSTEM

- Installation of the whole muon system at H8 in the North Area
- Energy calibration with 140, 180, 240, 300 GeV pion beam

First glance at the signal

Position resolution: $\sigma_x = 3.7$ cm

Extrapolated track $X$ position vs mean time difference between left and right side

LanGau fitted QDC histogram

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
<td>854</td>
</tr>
<tr>
<td>Mean</td>
<td>58.15</td>
</tr>
<tr>
<td>Std Dev</td>
<td>33.34</td>
</tr>
<tr>
<td>$\chi^2$/ndf</td>
<td>103.3 / 99</td>
</tr>
<tr>
<td>Prob</td>
<td>0.3637</td>
</tr>
<tr>
<td>Width (scale)</td>
<td>3.226 ± 0.293</td>
</tr>
<tr>
<td>mostProbable</td>
<td>41.24 ± 0.29</td>
</tr>
<tr>
<td>norm</td>
<td>708.2 ± 29.6</td>
</tr>
<tr>
<td>sigma</td>
<td>3.397 ± 0.578</td>
</tr>
</tbody>
</table>
SIMULATION

- **PRODUCTION**
  - pp collisions at LHC with DPMJET III - v10 (embedded in FLUKA)
  - $\sqrt{s} = 13$ TeV

- **PROPAGATION**
  - Detailed simulation of LHC beam line with FLUKA
  - Prediction of neutrino yields and spectra at SND@LHC location
  - Prediction of muon population in the upstream rock, 75m from SND@LHC

- **DETECTOR**
  - Neutrino interactions in SND@LHC material simulated with GENIE
  - Detector geometry and surrounding tunnel implemented in GEANT4
BACKGROUND ESTIMATION

Muon background

• Rates at the SND@LHC location:
  \[4 \times 10^4 \text{cm}^2/\text{fb}^{-1}\]

SND@LHC can perform precise measurements on muon yield and angle to validate predictions and constraint simulations in an unexplored region

• Measurements performed by FASER

From FASER TP
https://cds.cern.ch/record/2651328

<table>
<thead>
<tr>
<th>T118</th>
<th>T112</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1.2 \pm 0.4 \times 10^4)</td>
<td>(1.9 \pm 0.2 \times 10^4)</td>
</tr>
</tbody>
</table>
ν_e ENERGY ESTIMATION

- Estimation of ν_e energy combing information from SciFi (target region) and Scintillator bars (Muon System)
- The detector acts as a non-homogeneous calorimeter

\[ E_{\text{rec}} = A + B \times N\text{hits}_{\text{SciFi}} + C \times N\text{hits}_{\text{Bars}} \]

- Monte Carlo hits used in the current estimation
- Parameters A, B and C estimated via a gradient descent minimisation algorithm

Average resolution: 22%
KAON CONTRIBUTION TO $\nu_e$

- In order to extract the $\nu_e$+anti-$\nu_e$ component from charmed hadron decay, a statistical subtraction of K component has to be performed
- The K component dominates at low energies (E<200 GeV)
- Predictions from different generators show large uncertainties (factor 2)

- This operation affects the low energy portion of the spectrum where the number of observed neutrino is lower
- The subtraction of the K component introduces an additional systematic error of $\sim 20\%$

Courtesy of F. Kling
UNCERTAINTY IN PION/KAON CONTAMINATION

- The uncertainty in the knowledge of $\pi/k$ contamination has two contributions:

1. Production of $\pi/k$
2. Propagation along beamline

- Simulation of light meson production in forward region constrained by LHCf collaboration
- Agreement better than $10\%$ with EPOS generator for $p_T>300$ GeV

- Neutrinos in SND@LHC acceptance with $E>600$ GeV have $p_T>250$ MeV

![Graph showing neutrino distribution](image)

The uncertainty in the knowledge of $\pi/k$ contamination has two contributions:

1. Production of $\pi/k$

2. Propagation along beamline

Charged meson propagation performed with FLUKA and show very good agreement with measurements performed along the beamline.

Measurements performed by FASER in TI18 in agreement with FLUKA predictions $(2 \times 10^4/cm^2/fb^{-1})$ within errors.

SND@LHC will measure particle flux in TI18 with high accuracy, using different detectors.

D. Prelipcean and G. Lerner (CERN-EN-TI-BMI)
ADVANCED SND@LHC: DETECTOR LAYOUT

1) Target region:
   • Vertex identification and electromagnetic calorimeter
   • Thin sensitive layers interleaved with Tungsten plates
   • Replace emulsions with electronic trackers to cope with high intensity muon rates

2) Muon ID system and hadronic calorimeter
   • 10 interaction lengths

3) Magnet with two high-resolution tracking stations
   • Measure charge of the muon (ν_μ/anti-ν_μ, ν_τ/anti-ν_τ in the τ→μ channel)
   • 1 T field over 2 m length
COMPLEMENTARITY WITH FASERnu

- Pseudo-rapidity range: $\eta > 8.8$
- Main physics goals:
  - $\sim 2000 \nu_e, 7000 \nu_\mu, 50 \nu_\tau$ CC interactions expected \([\text{Eur. Phys. J. C 80 (2020) 61}]\)
  - NC measurements could constrain neutrino non-standard interactions \([\text{Phys. Rev. D 103, 056014 (2021)}}\]
  - Neutrino CC interaction with charm production ($\nu_s \rightarrow l c$)
  - Study the strange quark content
Possible contributions:
- Hardware – muon detector
- FLUKA simulations
- Data analysis.

+ 2 engineers + 2 technicians
Neutron shield: design and construction

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The neutron source is considered as a spherical surface 200 cm radius, neutrons are isotropically emitted in the space.

The neutron spectrum was provided by FLUKA team:

This FLUKA output will be used as the neutron probability distribution for the shielding simulation.
The tested shield was composed of an external layer made of Polyethylene (denoted as poly) plus an internal layer made of Borated Polyethylene 30% (denoted as polbor30%). We have simulated 1E9 primaries neutrons in all the studied cases.

Different configurations were tested:

- a) 1cm of Poly + 8cm of polbor30%
- b) 2cm of Poly + 7cm of polbor30%
- c) 3cm of Poly + 6cm of polbor30%
- d) 4cm of Poly + 5cm of polbor30%
- e) 5cm of Poly + 4cm of polbor30%
- f) 6cm of Poly + 3cm of polbor30%
- g) 7cm of Poly + 2cm of polbor30%
- h) 8cm of Poly + 1cm of polbor30%
- i) 9cm of Poly + 8cm of polbor30%
- j) 9cm of polbor5%
The final selected option is: 5cm of Plexi + 4cm of polbor30%

Neutron rejection for selected option. Here Ratio = Shielding/No-Shielding

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 ev</td>
<td>7.3E-05</td>
</tr>
<tr>
<td>&lt; 100 eV</td>
<td>1.5E-03</td>
</tr>
<tr>
<td>&lt; 10 keV</td>
<td>4.3E-03</td>
</tr>
<tr>
<td>&lt; 2 MeV</td>
<td>9.7E-03</td>
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<tr>
<td>&lt; 20 MeV</td>
<td>1.4E-02</td>
</tr>
<tr>
<td>&lt; 200 MeV</td>
<td>2.3E-02</td>
</tr>
<tr>
<td>&lt; 1 GeV</td>
<td>2.5E-02</td>
</tr>
</tbody>
</table>
Sebastian Andres Cepeda Godoy and Matias Liz Vargas (UNAB/SAPHIR) work on the ColdBox construction at CERN.