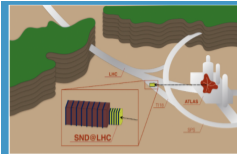
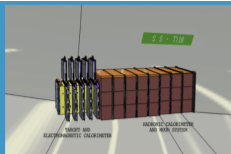


# SND@LHC: Scattering and Neutrino Detector at the LHC

Lesya Shchutska  
*École Polytechnique Fédérale de Lausanne*  
On behalf of the SND@LHC Collaboration



## SND-LHC: Scattering and Neutrino Detector at the LHC



A newly proposed, compact and stand-alone experiment designed to:

- perform measurements with neutrinos
- and search for new feebly interacting particles,

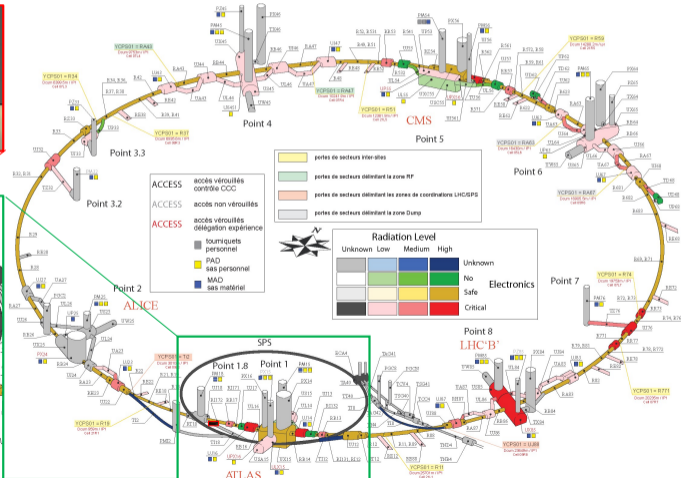
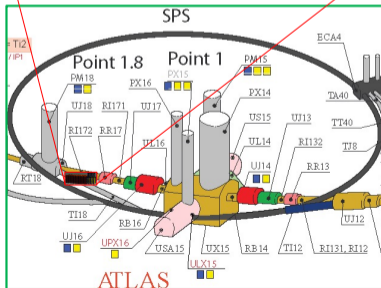
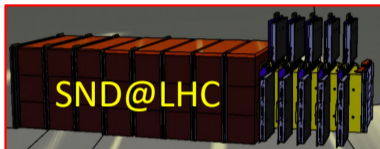
produced at the LHC, in an unexplored range of  $7.2 < \eta < 8.6$

- Letter of intent: [LHCC-I-037](#), 27 Aug 2020
- Technical proposal: [LHCC-P-016](#), 22 Jan 2021
- Experiment approval: [Grey Book database](#), 17 Mar 2021
- Experiment website: <http://snd-lhc.web.cern.ch/>
- First phase: operation in Run 3 to collect  $150 \text{ fb}^{-1}$

SND@LHC is currently a collaboration of 180 members from 20 institutes

## Location: (LEP) Injection Tunnel 18, TI18

- ~480 m away from the ATLAS IP: shielding from the IP provided by 100 m rock
- charged particles are deflected by the LHC magnets



# Detector design

Hybrid detector designed for:

- identification and measurement of the three neutrino flavours,  $\nu_e$ ,  $\nu_\mu$ ,  $\nu_\tau$
- detection of feebly interacting particles,  $\chi$

## 1 Veto plane to tag incoming muons

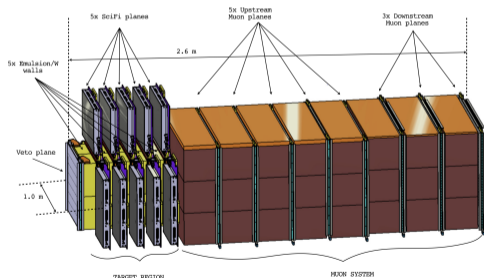
- scintillating bars

## 2 Target region for $\nu$ or $\chi$ scattering

- emulsion cloud chambers (emulsion and tungsten)
- SciFi (scintillating fibres) planes

## 3 Muon system for produced $\mu$ ID

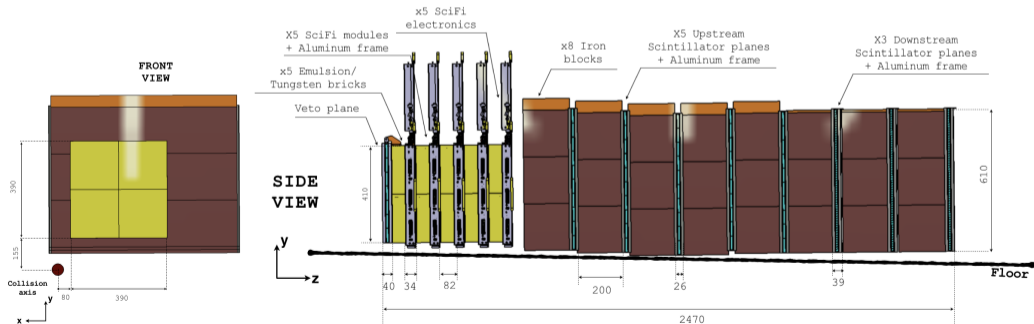
- iron walls interleaved with scintillating bars



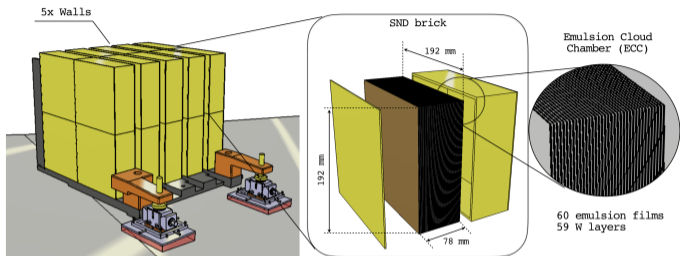


## Detector key numbers

- target: 830 kg of tungsten
- angular acceptance:  $7.2 < \eta < 8.6$ , off-axis location
- electromagnetic calorimeter:  $\sim 84X_0$ , sampling every  $17X_0$
- hadronic calorimeter:  $\sim 10\lambda$  (muon system alone –  $8\lambda$ ), sampling every  $\lambda$

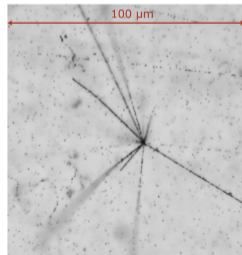
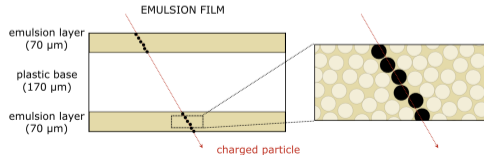


# Target and vertex detector: Emulsion



Emulsion cloud chamber (ECC) technique for the target: tungsten layers (1mm thick) alternated with nuclear emulsion films

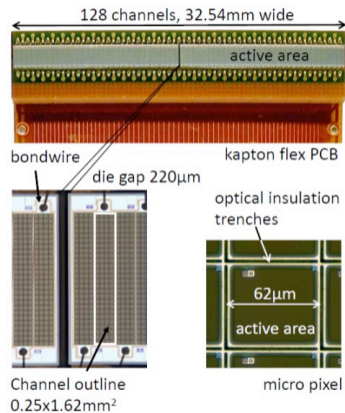
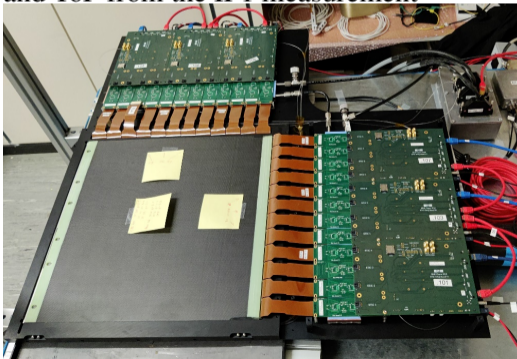
Submicrometric position resolution for event topology reconstruction:



## SciFi planes

5 *xy*  $390 \times 390\text{mm}^2$  SciFi planes used for:

- tracking and combining information from ECC
- active layers of sampling calorimeter for energy measurement
- timing information for global event reconstruction and ToF from the IP1 measurement



SiPM array for light detection:  
 $60\mu\text{m}$  spatial resolution

## Muon stations (+veto plane)

① upstream:

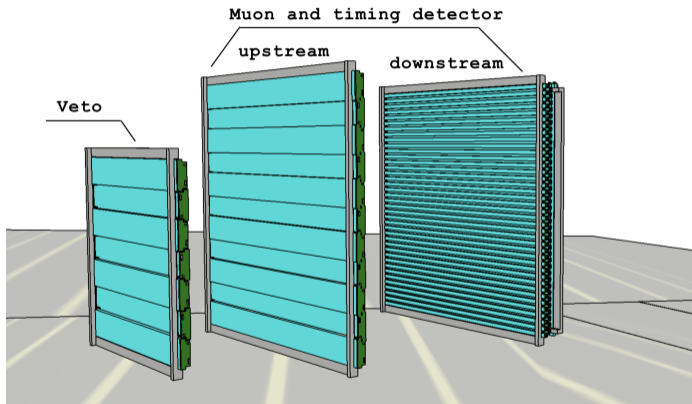
- 5 planes
- 10 bars per plane

⇒ HCAL

② downstream

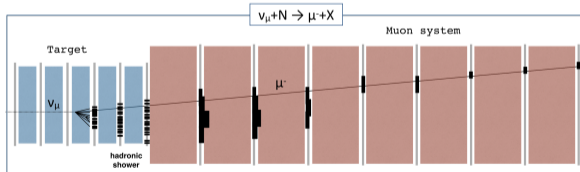
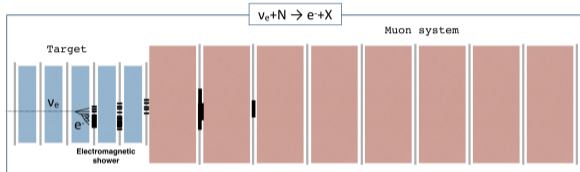
- 3 planes
- 2 layers per plane
- 60 bars layer

⇒  $\mu$  ID



## Event reconstruction: first phase

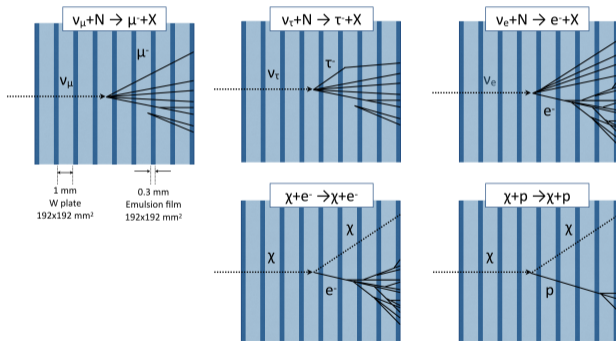
Using information from electronic detectors (veto, SciFi, muon system):



- identify neutral scattered candidates
- identify muons in the final state
- identify electrons/hadrons
- reconstruct EM and hadronic showers
- measure neutrino/ $\chi$  energy

## Event reconstruction: second phase

Using nuclear emulsions:



- identify EM showers
- $\nu/\chi$  vertex reconstruction and secondary search
- match with candidates from electronic detectors
- complement SciFi for EM energy measurement

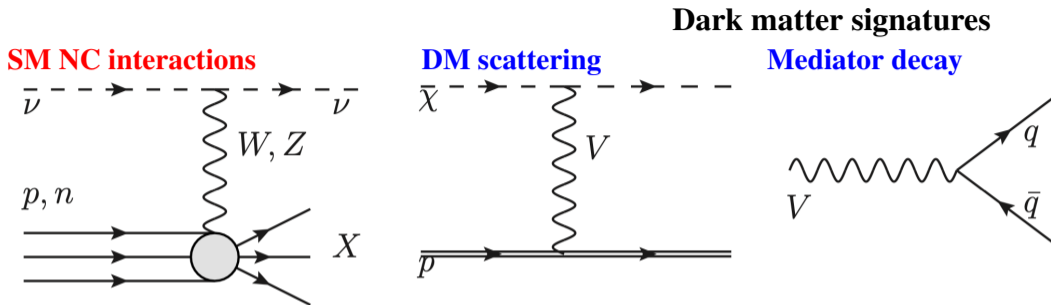
## Neutrino physics in Run 3

$\nu$  production with DPMJET3, propagation with FLUKA, interaction with GENIE:

Flavour	Neutrinos in acceptance		CC neutrino interactions		NC neutrino interactions	
	$\langle E \rangle$ [GeV]	Yield	$\langle E \rangle$ [GeV]	Yield	$\langle E \rangle$ [GeV]	Yield
$\nu_\mu$	145	$2.1 \times 10^{12}$	450	730	480	220
$\bar{\nu}_\mu$	145	$1.8 \times 10^{12}$	485	290	480	110
$\nu_e$	395	$2.6 \times 10^{11}$	760	235	720	70
$\bar{\nu}_e$	405	$2.8 \times 10^{11}$	680	120	720	44
$\nu_\tau$	415	$1.5 \times 10^{10}$	740	14	740	4
$\bar{\nu}_\tau$	380	$1.7 \times 10^{10}$	740	6	740	2
TOT		$4.5 \times 10^{12}$		1395		450

Neutrino physics programme detailed in the technical proposal [LHCC-P-016](#):

Measurement	Uncertainty		Signal/Background
	Stat.	Sys.	
$pp \rightarrow \nu_e X$ cross-section	5%	15%	
Charmed hadron yield	5%	35%	
$\nu_e/\nu_\tau$ ratio for LFU test	30%	22%	
$\nu_e/\nu_\mu$ ratio for LFU test	10%	10%	
NC/CC ratio	5%	10%	
Observation of high-energy $\nu_\tau$			4



- ① DM scattering in the target volume:  $pp \rightarrow V + X, V \rightarrow \chi\chi$ 
  - **elastic:** background-free signature with one charged track  $\chi + p/e \rightarrow \chi + p/e$
  - **inelastic:**  $\chi + p/n \rightarrow \chi + X$  signature is similar to  $\nu$  NC  
 $\implies$  exploit kinematical features, look for an excess in NC events
- ② visible mediator decay within the detector volume:  $V \rightarrow q\bar{q}$ :
  - look for an isolated decay vertex
  - exploit time of flight from the IP1 (480 m)

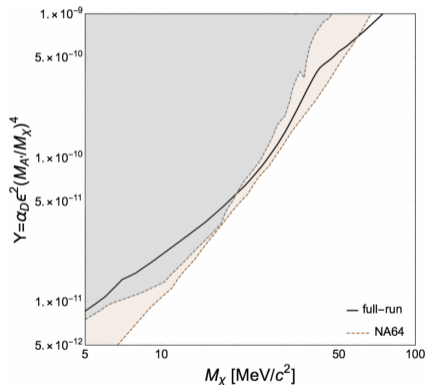


## Scattering off atomic electrons ( $150 \text{ fb}^{-1}$ )

Vector portal in a minimal SM extension, with the production of a dark photon  $\mathcal{A}'$ :

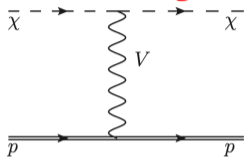
$$\mathcal{L}_{\mathcal{A}'} = -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{m_{\mathcal{A}'}^2}{2}A'^{\mu}A'_{\mu} - \frac{1}{2}\epsilon F'_{\mu\nu}F^{\mu\nu} \quad (1)$$

- $\mathcal{A}' \rightarrow \chi\chi$ , with  $\chi + e \rightarrow \chi + e$  in the target
- study with full simulation: 0 SM background expected
- sensitivity dominated by small couplings: DM scattering acquires additional  $\epsilon^2$  in the yield  
 $\implies$  SND@LHC is an  $\epsilon^4$  experiment
- NA64 is an  $\epsilon^2$  experiment  
 $\implies$  has better sensitivity

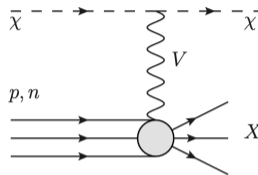


## Scattering off nucleons

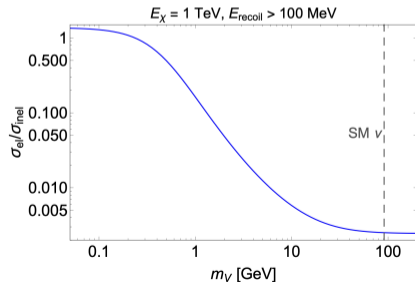
### elastic scattering



### inelastic scattering



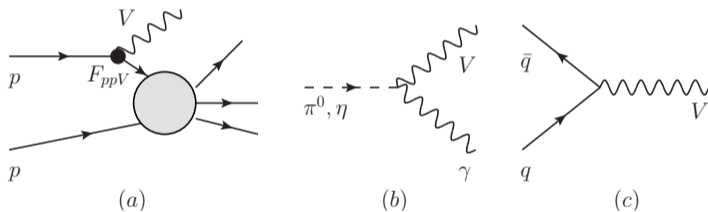
- the ratio of cross sections  $\sigma_{\text{el}}/\sigma_{\text{inel}}$  drops with the mediator mass
- for SM neutrinos, mediator (Z) is heavy  $\implies$  most of events are inelastic, only  $\mathcal{O}(1)$  of elastic events is expected at SND@LHC during Run 3
- elastic scattering off protons is background-free
- deep inelastic scattering (DIS) off nucleons is important for heavier mediators



## Leptophobic portal

Leptophobic portal is currently less constrained:

$$\mathcal{L}_{\text{leptophob}} = -g_B V^\mu J_\mu^B + g_B V^\mu (\partial_\mu \chi^\dagger \chi + \chi^\dagger \partial_\mu \chi), \quad J_\mu^B = \frac{1}{3} \sum_q \bar{q} \gamma_\mu q \quad (2)$$



Similarly to dark photon, the mediator is produced:

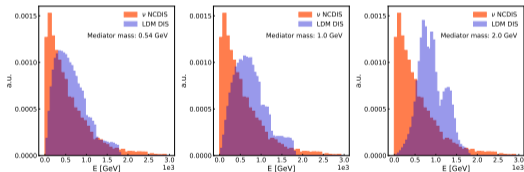
- ① by proton bremsstrahlung:  $p + p \rightarrow V + X$
- ② in decays of unflavored mesons  $\pi, \eta$ :  $\pi \rightarrow V + \gamma, \quad \eta \rightarrow V + \gamma$
- ③ by Drell-Yan process:  $q + \bar{q} \rightarrow V + X$

# Leptophobic portal sensitivity ( $150 \text{ fb}^{-1}$ )

## 1 elastic scattering:

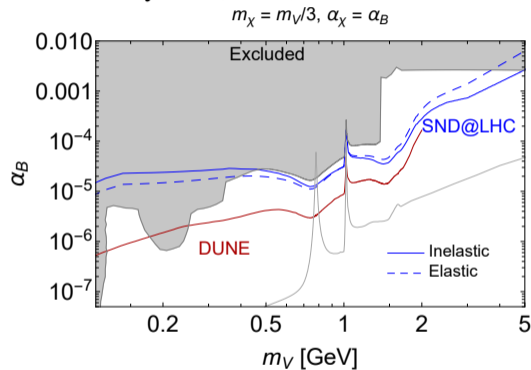
	$\chi p \rightarrow \chi p$	
	Selection eff.	Background
NC DIS	$2.8 \times 10^{-3}$	1.26
NC RES	$1.7 \times 10^{-1}$	0.48

## 2 inelastic scattering:



- kinematic selection alone does not suppress SM bkg
- sensitivity is based on  $3\sigma$  signal excess over SM bkg

Excluded: by CDF, BES, E949 and BNL



## Summary and outlook

- SND@LHC experiment is approved and is quickly advancing with construction
- commissioning and energy calibration for electronic detectors in September
- physics studies for SM and NP searches programme are ongoing



- bonus phenomenological estimates sensitivity to FIPs in [arXiv:2104.09688](https://arxiv.org/abs/2104.09688)