Possible μ-decay Beams for Sterile Physics in the 2010s

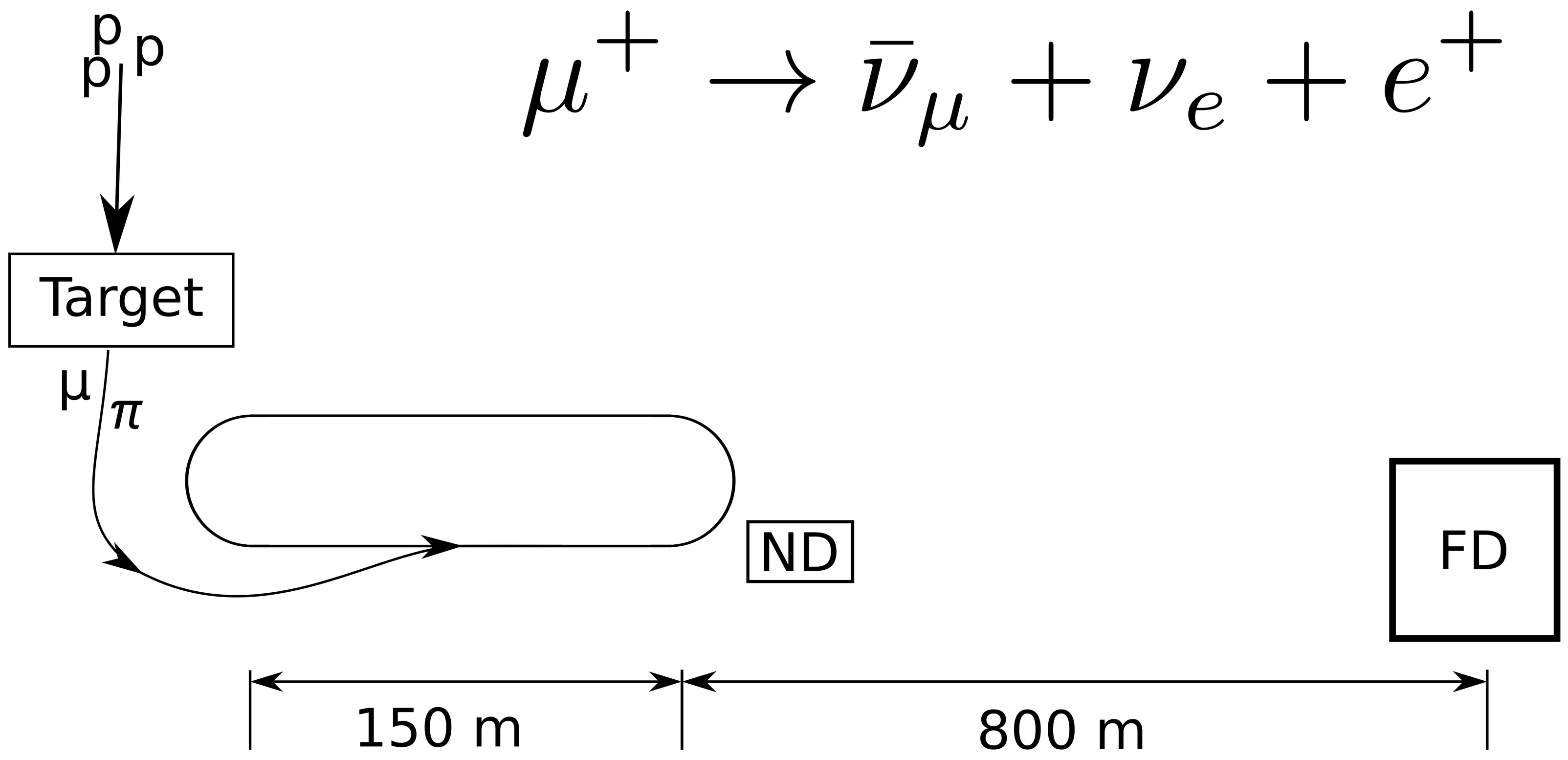
π-decay beams are *so* 1990s

Christopher D. Tunnell   on behalf of the νSTORM collaboration
Subdepartment of Particle Physics, University of Oxford, Keble Road, Oxford, OX1 3RH, UK

Abstract

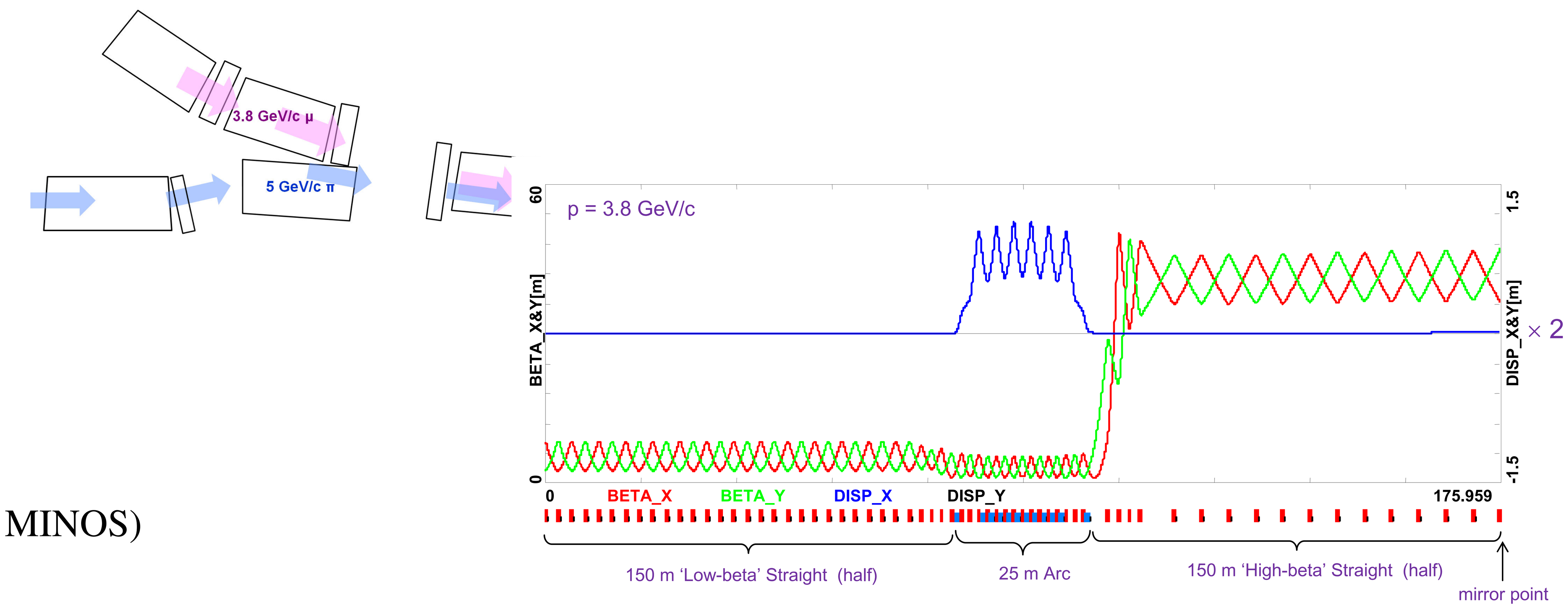
There are strong theoretical motivations for the existence of sterile neutrinos and experimental motivations for measuring muon and electron neutrino cross sections. A possible facility and experiment will be discussed that can do both of these physics. Protons are extracted onto a target to create pions, which subsequently decay to 3.8 GeV/c muons that would be stored in a ring with 150 m straights. There is **no acceleration or new technology**. These muons will decay and create electron and muon neutrinos. A near detector at 20-50 metres measures cross sections of both flavours and a 1 kt magnetised far detector at 800 m gives sterile sensitivity. There is a $> 10\sigma$ sensitivity to the LSND anomaly.

$$\mu^+ \rightarrow \bar{\nu}_\mu + \nu_e + e^+$$



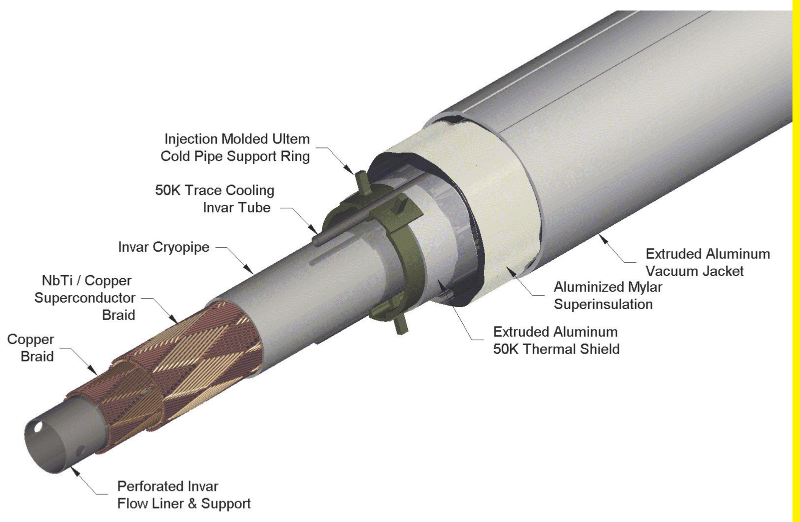
Accelerator

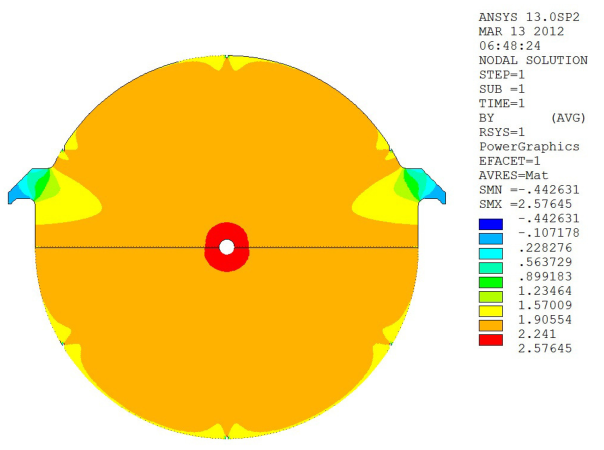
- 60 GeV/c protons on 100 kilowatt target station
- 2×10^{18} muons for 10^{21} POT, 0.1 π per POT
- 70 cm beryllium target, $\pi < 120$ mrad
- 5 GeV/c $\pi \rightarrow$ 3.8 GeV/c μ; $p \pm 10\%$
- 150 meter decay straight



Detector:

- 1 kt sampling iron calorimeter at 800 m (think MINOS)
- 5m x 5m x 1 cm plates
- Magnetized using SCTL
- 2 T field throughout plate
- SiPM read-out





$$P_{\nu_e \rightarrow \nu_\mu} = \quad 4|U_{e4}|^2|U_{\mu4}|^2 \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right), \quad (1)$$

$$P_{\nu_\alpha \rightarrow \nu_\alpha} = 1 - \left[4|U_{\alpha4}|^2(1-|U_{\alpha4}|^2)\right] \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right). \quad (2)$$

Channel	$N_{\text{osc.}}$	N_{null}	Diff.	$(N_{\text{osc.}} - N_{\text{null}})/\sqrt{N_{\text{null}}}$
$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ CC	184	0	∞	∞
$\bar{\nu}_e \rightarrow \bar{\nu}_e$ NC	179142	182276	-1.7%	-7.3
$\nu_\mu \rightarrow \nu_\mu$ NC	382913	387924	-1.3%	-8.0
$\bar{\nu}_e \rightarrow \bar{\nu}_e$ CC	455566	463385	-1.7%	-11.5
$\nu_\mu \rightarrow \nu_\mu$ CC	1143355	1157784	-1.2%	-13.4
$\sum$NC				-10.8

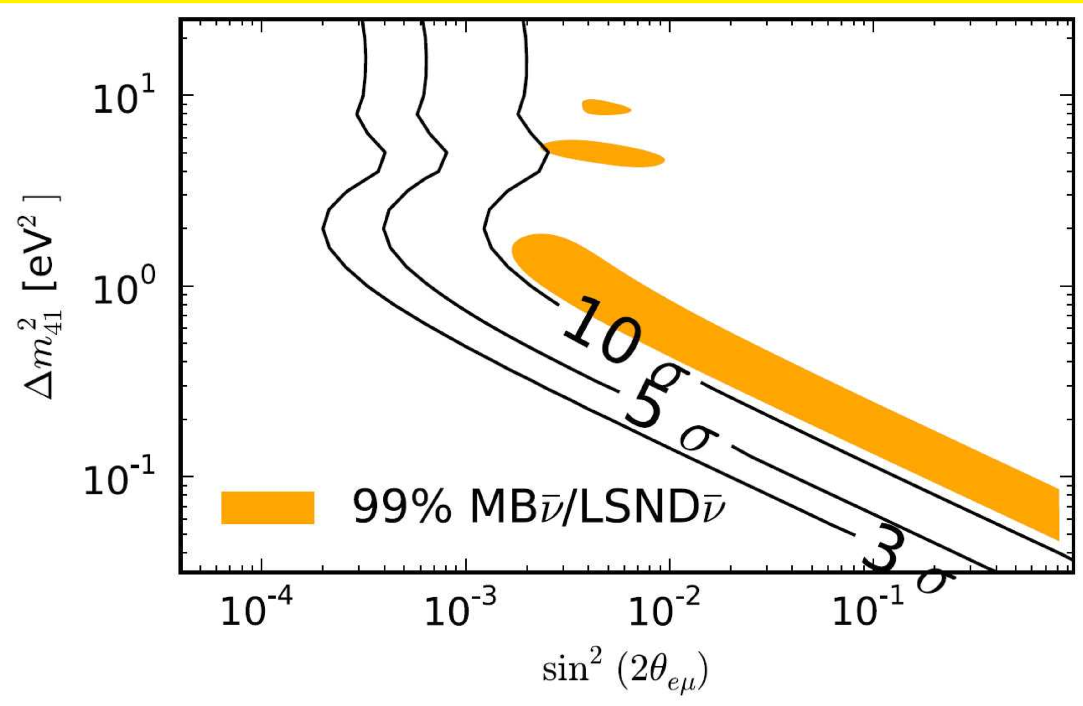
(a) Neutrino-mode with stored μ^-.

Channel	$N_{\text{osc.}}$	N_{null}	Diff.	$(N_{\text{osc.}} - N_{\text{null}})/\sqrt{N_{\text{null}}}$
$\nu_e \rightarrow \nu_\mu$ CC	418	0	∞	∞
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ NC	212473	215078	-1.2%	-5.6
$\nu_e \rightarrow \nu_e$ NC	334075	340399	-1.9%	-10.8
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ CC	544945	551521	-1.2%	-8.9
$\nu_e \rightarrow \nu_e$ CC	978685	996433	-1.8%	-17.8
$\sum$NC				-12.0

(b) If anti-neutrino-mode with stored μ^+.

$\nu_e \rightarrow \nu_\mu$ Sensitivity:

- Signal efficiency 60%
- 10^{-4} NC and charge misidentification backgrounds
- 2% normalisation and 35% background uncertainty
- 10σ sensitivity to LSND anomaly
- $\nu_e \rightarrow \nu_\mu = CPT(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$

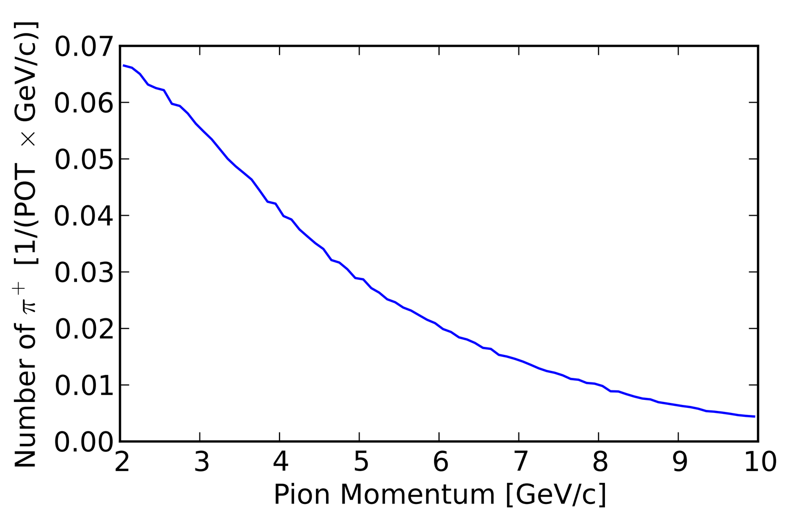


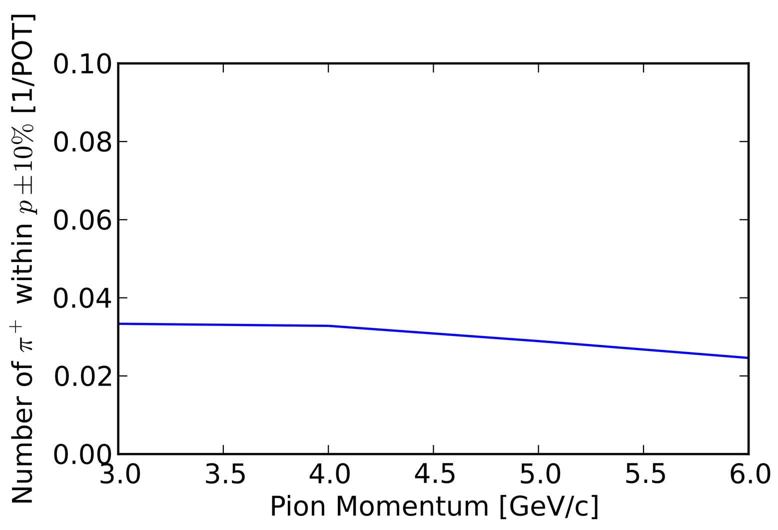
What could be done at CERN's PS using Liquid Argon?

How many muon decays?

- Based on CERN-ATS-2011-193
- PS with 20 GeV/c, 70 cm beryllium target
- 5×10^{20} POT: 5 years of 9.2×10^{19} POT per year
- πs within 120 mrad, 0.03 π per POT, $p \pm 10\%$
- 3×10^{17} muons
- Rest same as above: 1 kt, 800 m, etc.

$$\begin{aligned} N_\mu &= (\text{POT}) \times (\pi \text{ per POT}) \times \epsilon_{\text{collection}} \times \epsilon_{\text{transport}} \times \epsilon_{\text{injection}} \times (\mu \text{ per } \pi) \times A_{\text{dynamic}} \times \Omega \\ &= 5 \times 10^{20} \times 0.03 \times 0.9 \times 1 \times 0.9 \times 0.07 \times 0.9 \times 0.375 \\ &= 3 \times 10^{17} \text{ good muon decays} \end{aligned}$$





How many events?

Channel	$N_{\text{osc.}}$	N_{null}	Diff.	$(N_{\text{osc.}} - N_{\text{null}})/\sqrt{N_{\text{null}}}$
$\bar{\nu}_e \rightarrow \bar{\nu}_e$ NC	31509	32062	-1.7%	-3.1
$\nu_\mu \rightarrow \nu_\mu$ NC	67364	68248	-1.3%	-3.4
$\bar{\nu}_e \rightarrow \bar{\nu}_e$ CC	80131	81509	-1.7%	-4.8
$\nu_\mu \rightarrow \nu_\mu$ CC	201141	203686	-1.2%	-5.6
$\sum$NC				-4.5

(a) Neutrino-mode with stored μ^-.

Channel	$N_{\text{osc.}}$	N_{null}	Diff.	$(N_{\text{osc.}} - N_{\text{null}})/\sqrt{N_{\text{null}}}$
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ NC	37378	37837	-1.2%	-2.4
$\nu_e \rightarrow \nu_e$ NC	58763	59878	-1.9%	-4.6
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ CC	95864	97024	-1.2%	-3.7
$\nu_e \rightarrow \nu_e$ CC	172146	175275	-1.8%	-7.5
$\sum$NC				-5

(b) If anti-neutrino-mode with stored μ^+.

Acknowledgements: In addition to the work created by the author, the work presented here includes that from Sergei Striganov, David Neuffer, Alex Bogacz, Alan Bross, and Bob Wands. The GLoBES authors are also thanked. And a special thanks to Simone Gilardoni for teaching me details about the CERN accelerator complex.