# Dark Photon physics in SBND


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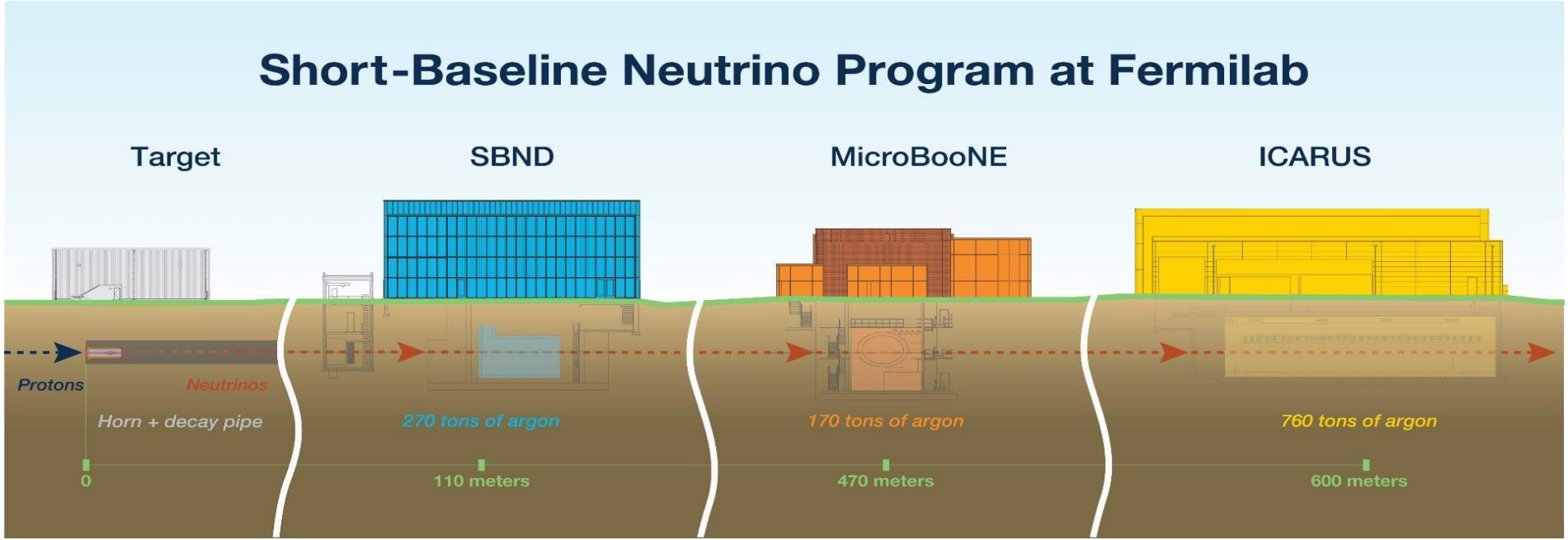
# SBN



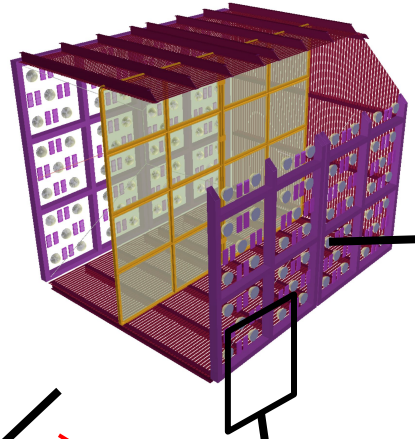

SBN program involves three LArTPC neutrino detectors placed on the Booster Neutrino Beam (BNB) axis.

- Neutrino oscillation
- Sterile neutrino hypothesis
- BSM physics

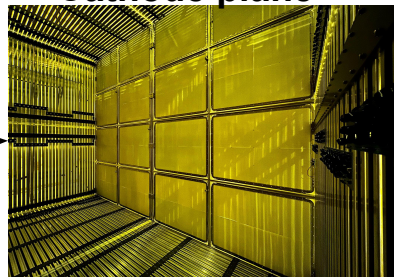
# Short Baseline Near Detector

The TPC :

- 4m × 4m in the transverse plane
- 5m along the beam axis
- Two drift volumes
- 3D event reconstruction
- 3mm position resolution
- Low momentum tresholds



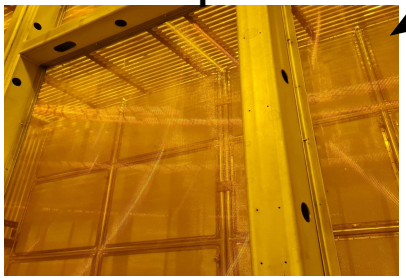
Cathode plane

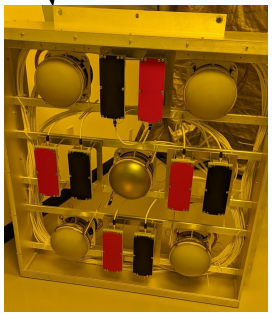


500 V/cm

Each consists of 3 planes of wires with 3 mm spacing and different angle per plane.

Anode plane

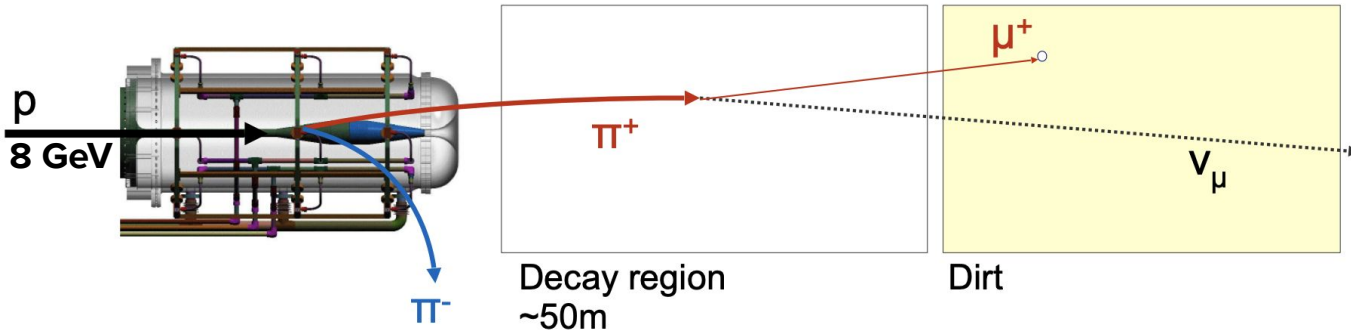


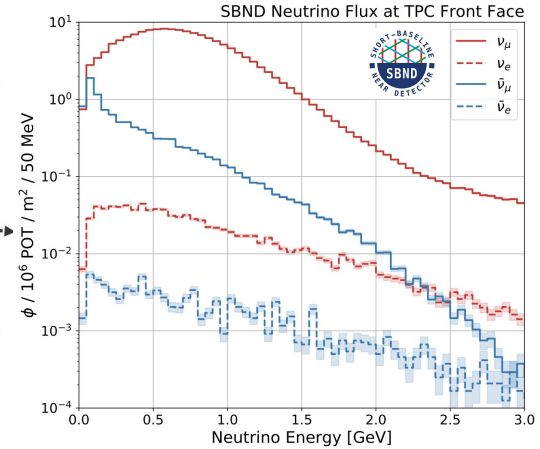


24 boxes for the PMT system

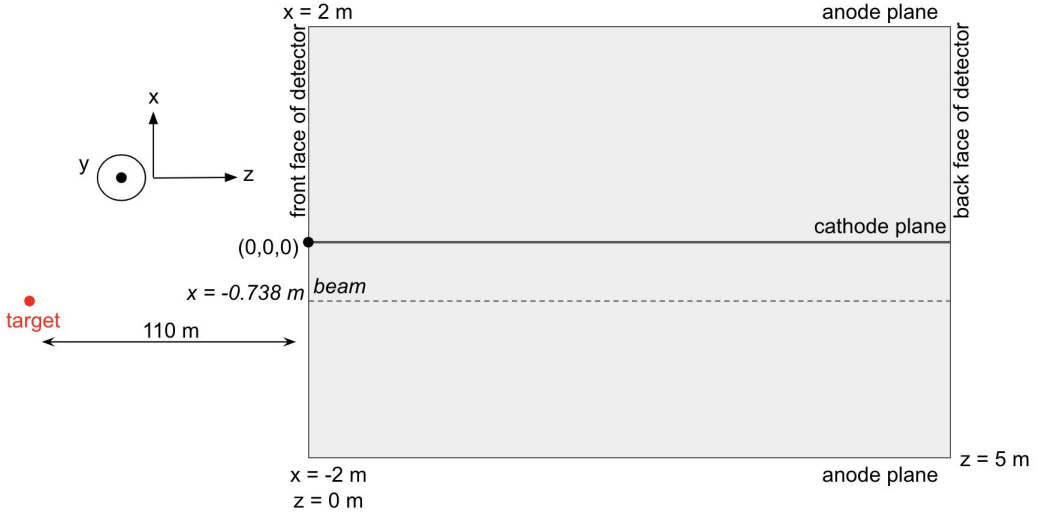
# Booster Neutrino Beam

Image credit: Zarko Pavlovic

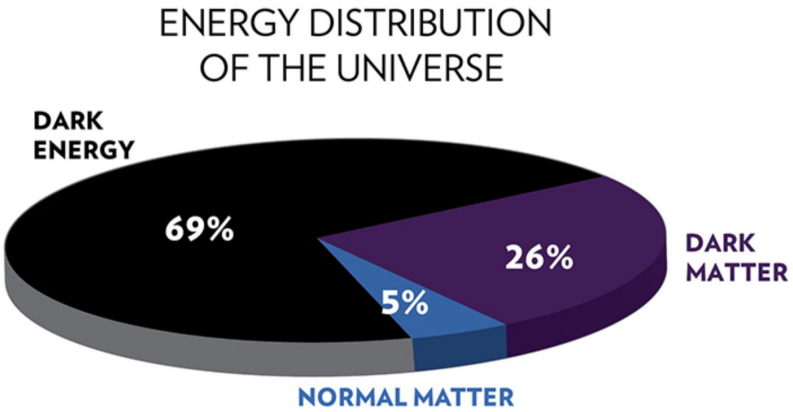



- $\langle E_\nu \rangle$ ~ 800 MeV.
- **10-18 X $10^{20}$ POT/yr**
- BSM phenomena in the beam



# Dark Matter



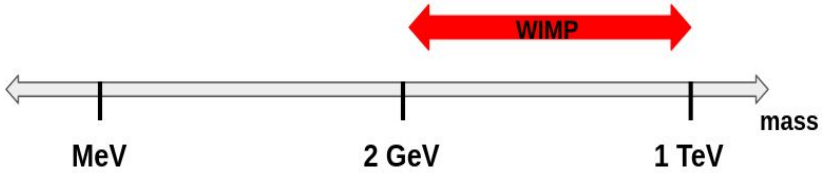

All our evidence for DM comes from its gravitational influence on visible matter

**Particle physics approach**

- Uncharged
- Non-relativistic and stable
- Very weakly interacting with itself and with visible matter

# WIMP's model

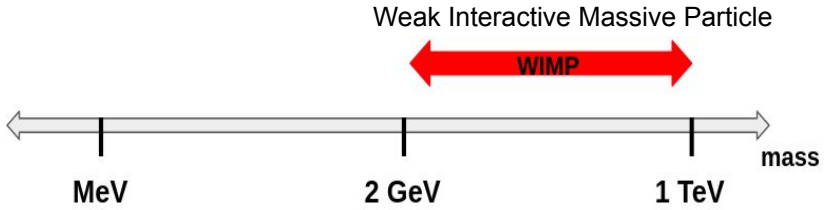
The model of Weak Interactive Massive Particle (WIMP) assume dark matter candidates as particles with a mass greater than 2GeV that interact by mean of the Weak force.



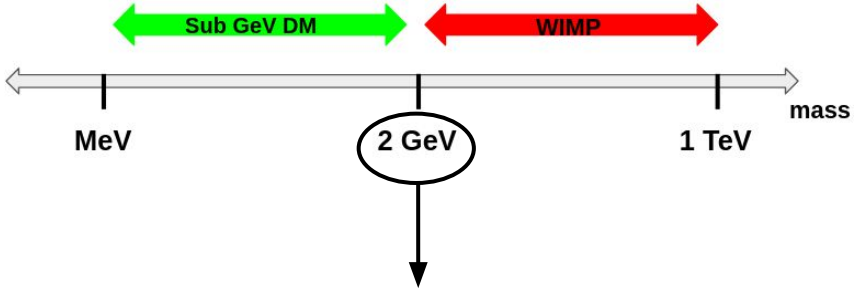

The theoretical model suggests that these particles formed following the Big Bang during the hottest and densest phases in the history of the universe. The high mass range is due to the high energies available during this period.

As a consequence of the universe expansion and subsequent cooling, WIMPs would have cooled down, reaching thermal equilibrium with the standard model plasma and interacting with it through the weak interaction.

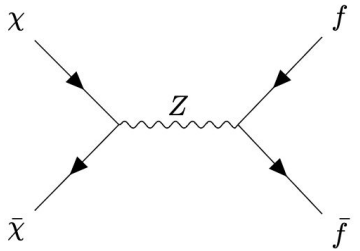
$$f(t,\vec{x},\vec{p}) = f_{GCE}(E) = \left[e^{(E-\mu_i)/T_i} \mp 1\right]^{-1} \longrightarrow \Omega \sim \frac{1}{\sigma}$$




- Thermal relic model
- WIMP's miracle $\Omega \sim 1/\sigma$ ($\Omega$ = abundance)




**Lee-Weinberg bound**




$$L \sim G_F(\bar{\chi}\gamma^\mu\chi)(\bar{f}\gamma^\mu f)$$

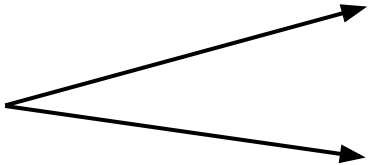
$$\sigma \sim \frac{G_F^2 m_\chi^2}{\pi} \sim 1pb\left(\frac{m_\chi}{5GeV}\right)^2$$

# SubGeV Dark Matter

According to thermal relic model a new interaction is needed in order to have a SubGeV DM candidate.

New gauge boson !

**Dark photon**



DM interaction

DM/SM interaction

Model parameters

- $m_V$
- $m_\chi$ < 2 GeV
- $\varepsilon$, kinetically mixing parameter.

# Dark photon: Vector Portal

The gauge symmetry employed is U(1)', and we are able to apply the Higgs mechanism, resulting in a non-zero mass associated with the dark photon

In order to allows the dark photon to transform into a standard model photon we introduce the concept of a **kinetically mixing parameter ε**

$U(1)_Y \sim U(1)_{em}$ ⟶

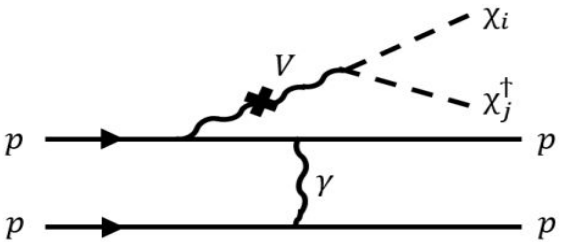
$$L = \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu} + \\ + eA_\mu J^\mu_{em} + d_D V_\mu J^\mu_D + \frac{1}{2}m_V^2 V_\mu V^\mu$$

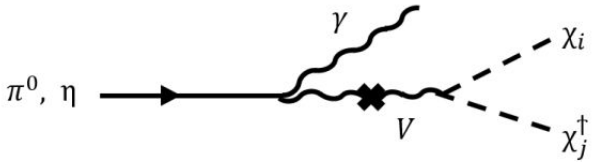
$$V \longrightarrow V$$
$$A \longrightarrow A + \epsilon V$$

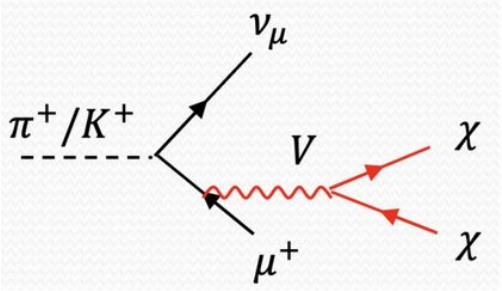
⟶

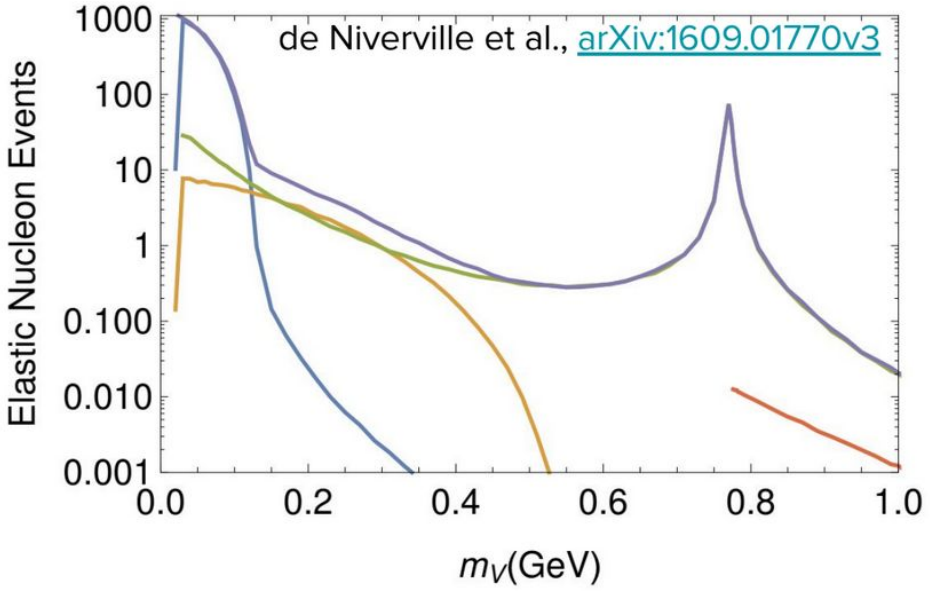
$$eA_\mu J^\mu_{em} \longrightarrow eA_\mu J^\mu_{em} + \boxed{\epsilon e V_\mu J^\mu_{em}}$$

**Dark millicharge**

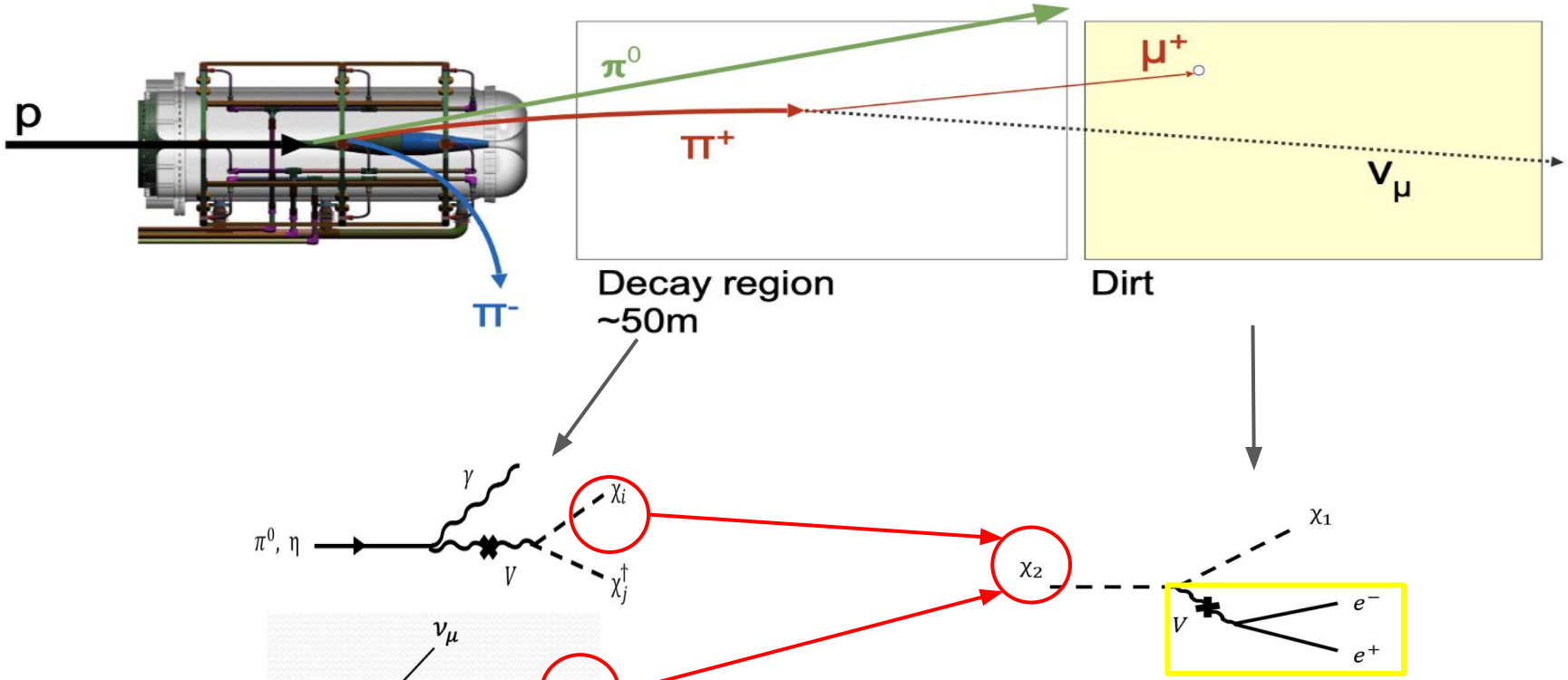

$\chi_i$
$V$
$\chi_j^\dagger$
$p$
$p$
$\gamma$
$p$
$p$

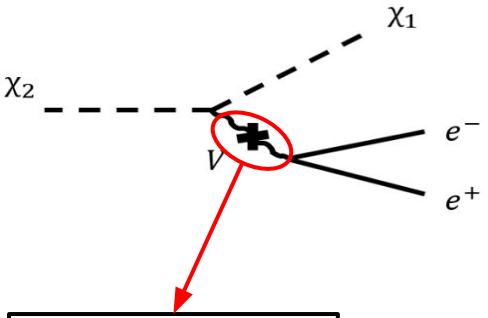

$\gamma$
$\chi_i$
$\pi^0$, $\eta$
$V$
$\chi_j^\dagger$


$\nu_\mu$
$\pi^+/K^+$
$V$
$\chi$
$\mu^+$
$\chi$

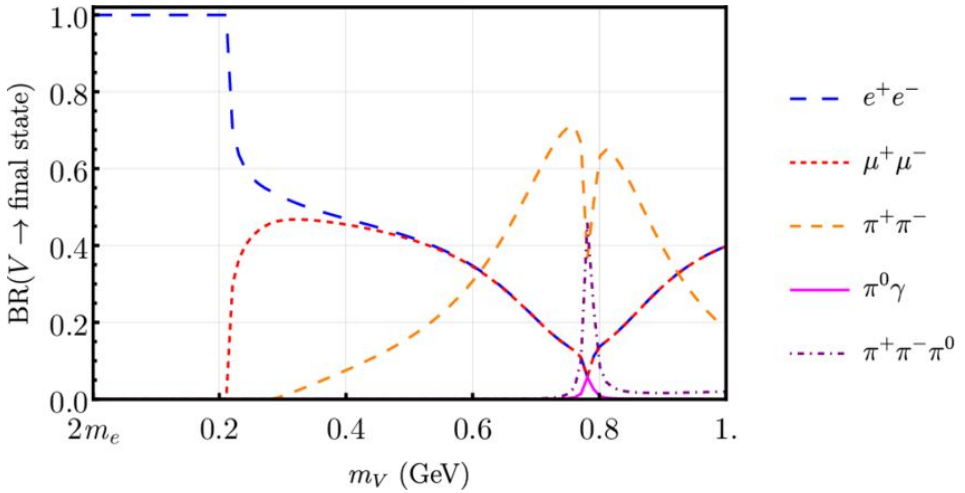

de Niverville et al., arXiv:1609.01770v3
Elastic Nucleon Events
1000
100
10
1
0.100
0.010
0.001
0.0
0.2
0.4
0.6
0.8
1.0
$m_V$(GeV)
$\pi^0$ Decay
$\eta$ Decay
Bremsstrahlung
Parton
Total

# DM decay





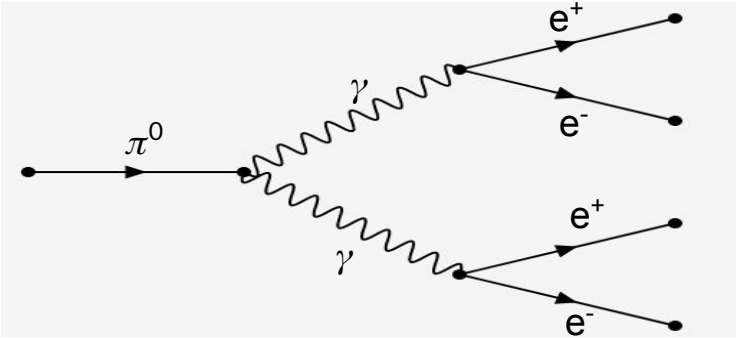

- 0.2 GeV
- 0.3 GeV
- 0.4 GeV

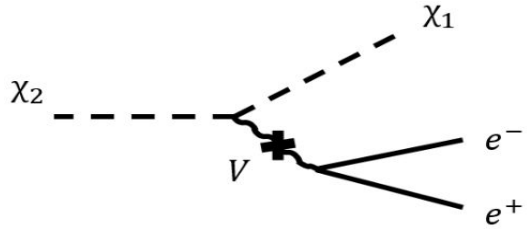



https://arxiv.org/abs/2206.02802

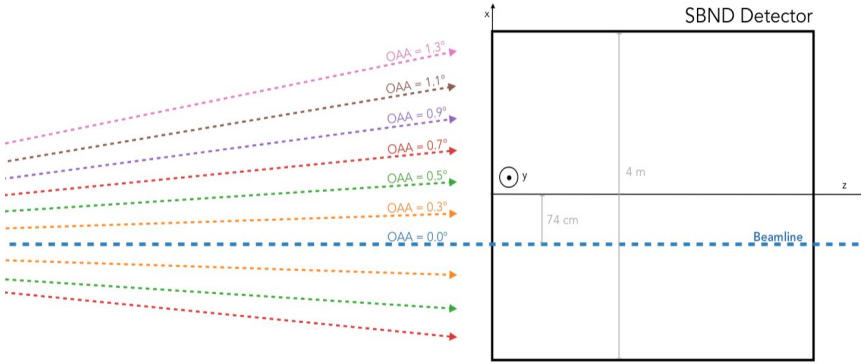
# Background ⟹ NC $\pi^0$

Neutrino interaction with the Argon nuclei




Event selection needed ⟹



# About the $e^+e^-$ selection

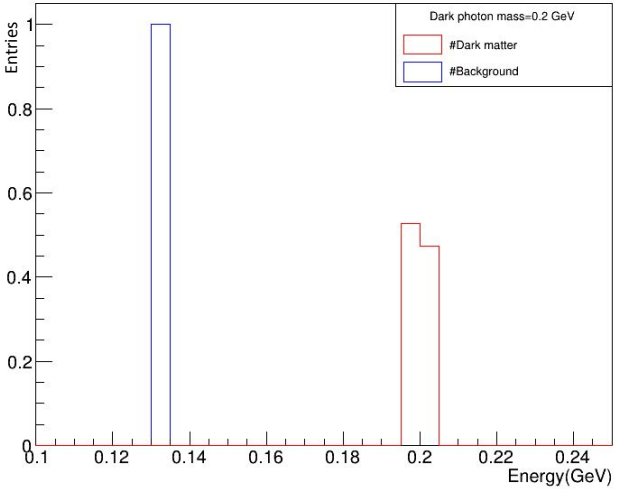
VertX1 - 1 cm < VertX2 < VertX1 + 1 cm

VertY1 - 1 cm < VertY2 < VertY1 + 1 cm

VertY1 - 1 cm < VertZ2 < VertZ1 + 1 cm

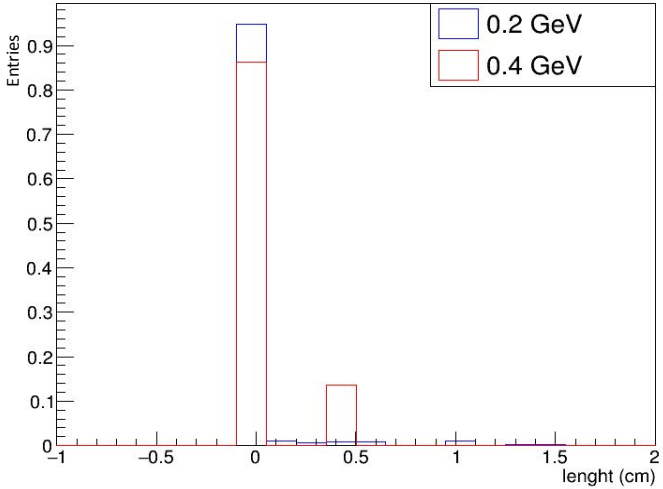
+ Fiducial Volume → The two particles are an $e^+e^-$ pair !

Invariant mass SBND simulation in progress

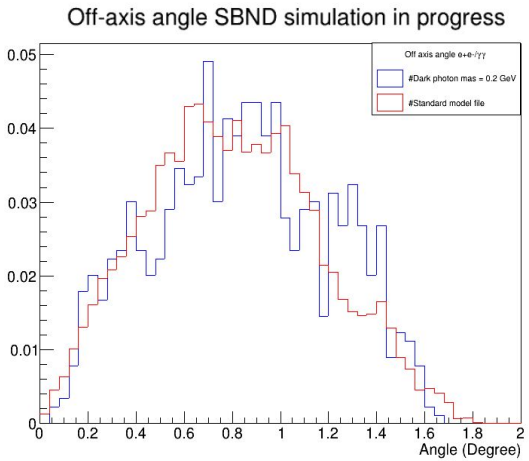


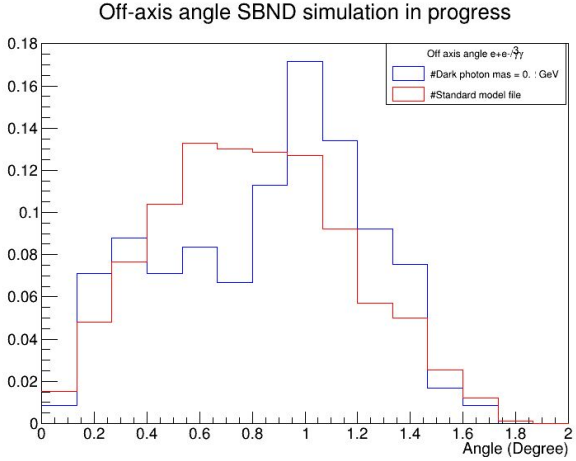

Norm of vectorial difference

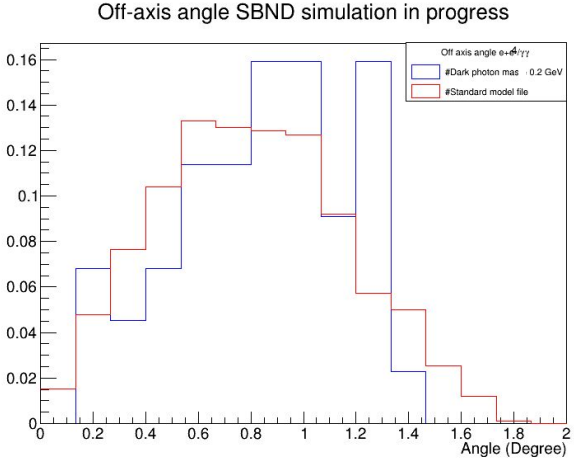
SBND simulation in-progress



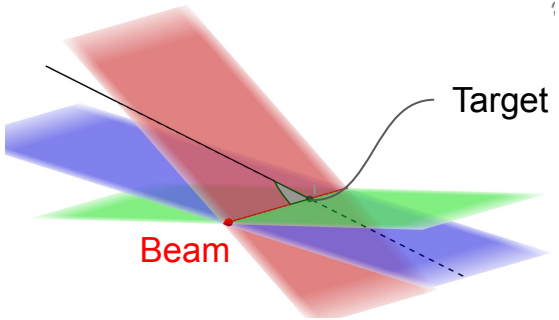
# PRISM measures ⟶ Off-Axis angle



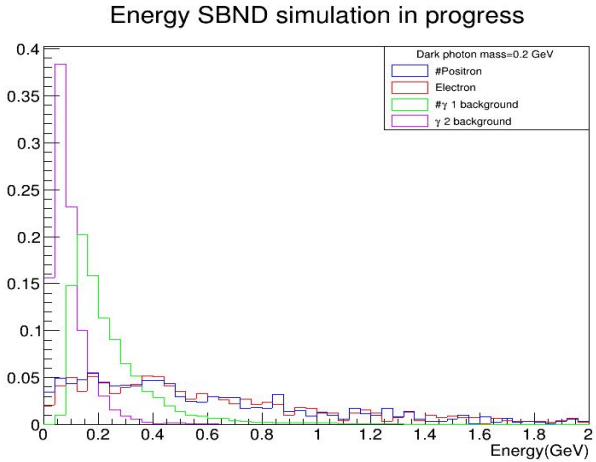



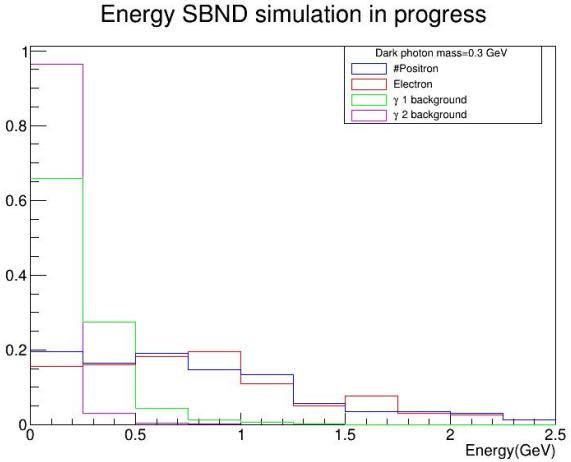

$\varepsilon=10^{-7}$

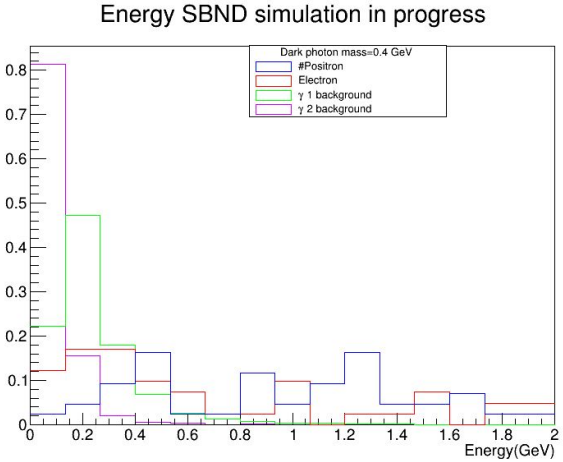



$$\text{Efficiency} = \frac{\text{Events selected}}{\text{Total events}}$$

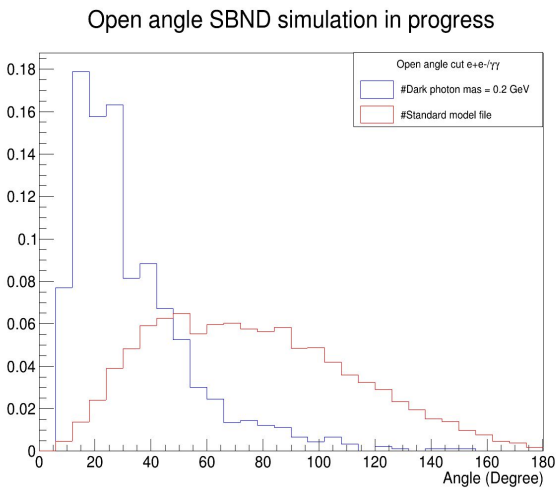
# Energy distribution

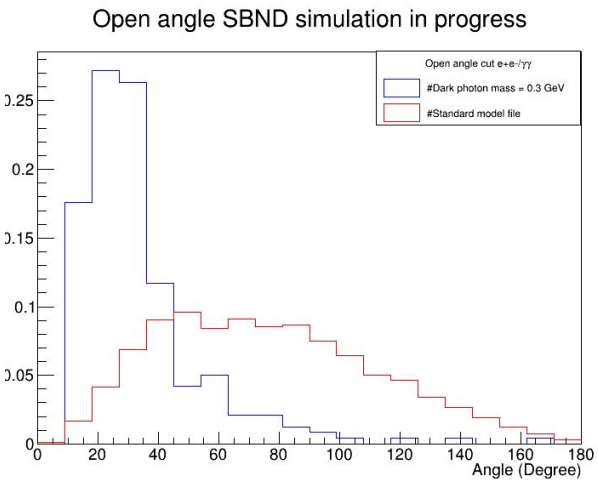


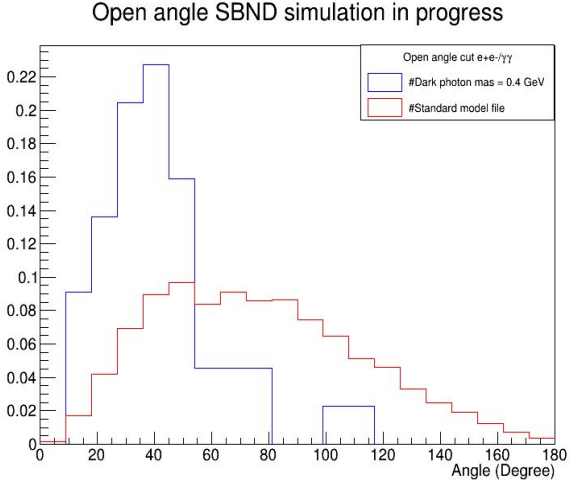



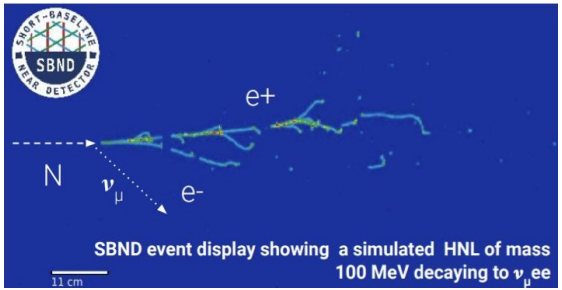



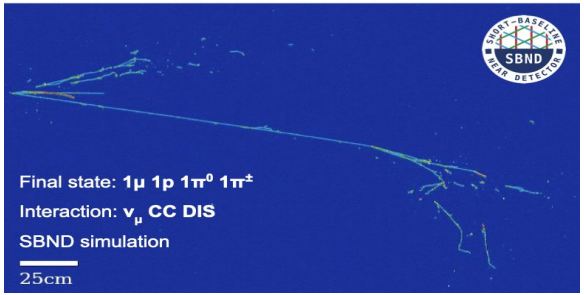
# Open angle distribution

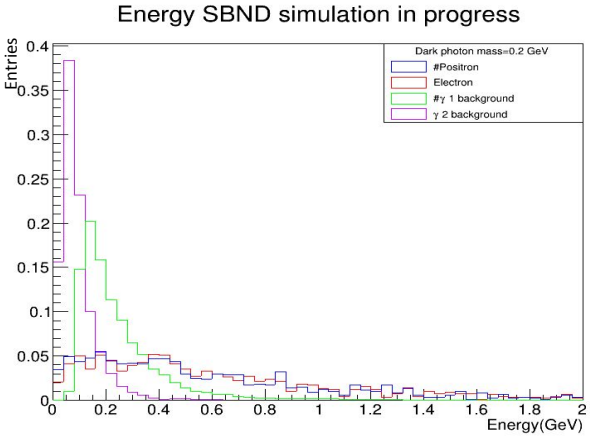


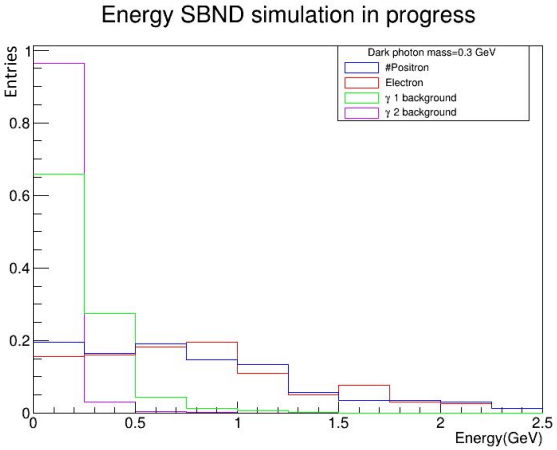



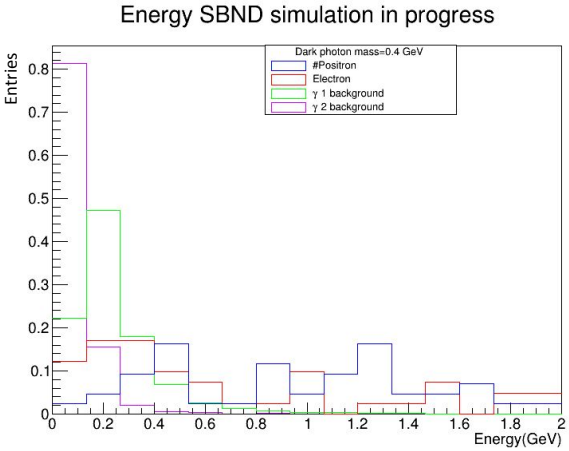



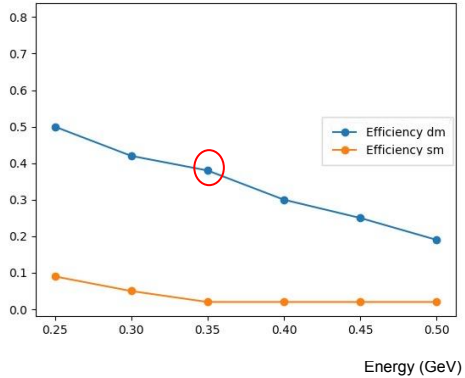



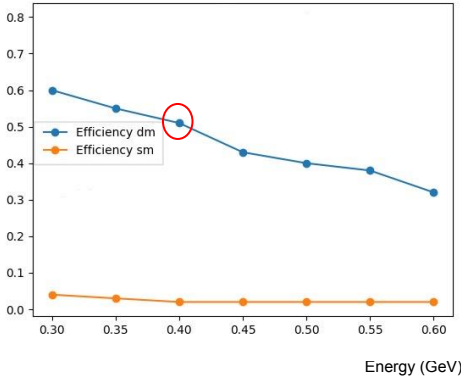



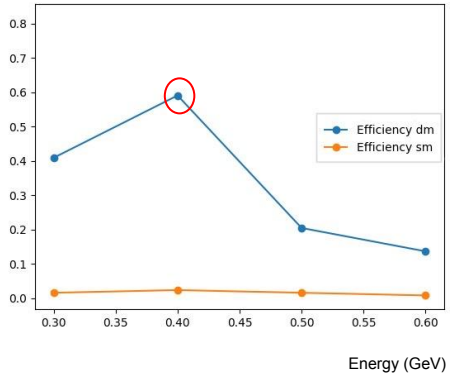

Energy SBND simulation in progress
Dark photon mass=0.2 GeV
#Positron
Electron
#γ 1 background
γ 2 background
Entries
Energy(GeV)

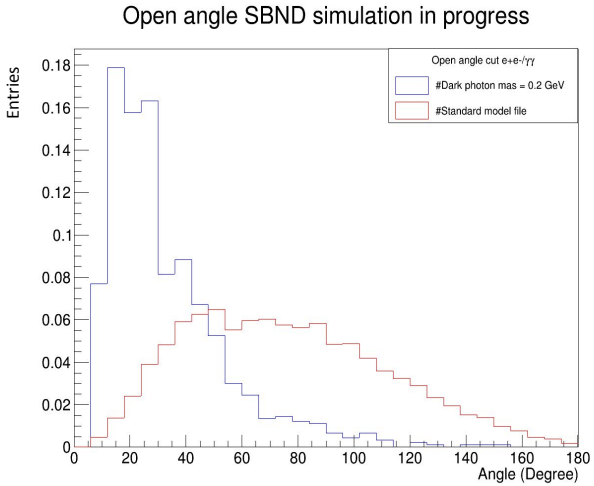

Energy SBND simulation in progress
Dark photon mass=0.3 GeV
#Positron
Electron
γ 1 background
γ 2 background
Entries
Energy(GeV)

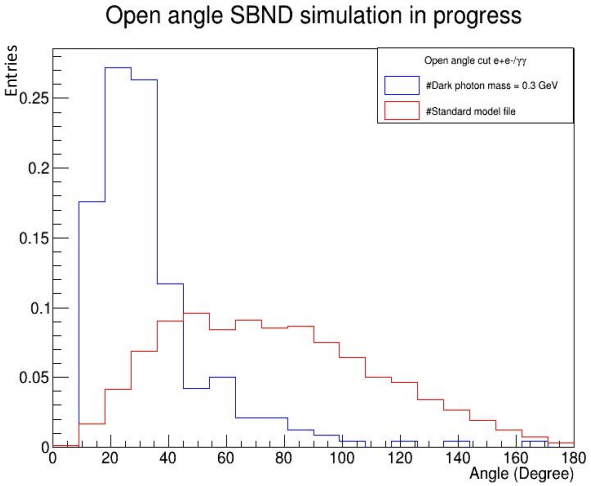

Energy SBND simulation in progress
Dark photon mass=0.4 GeV
#Positron
Electron
γ 1 background
γ 2 background
Entries
Energy(GeV)

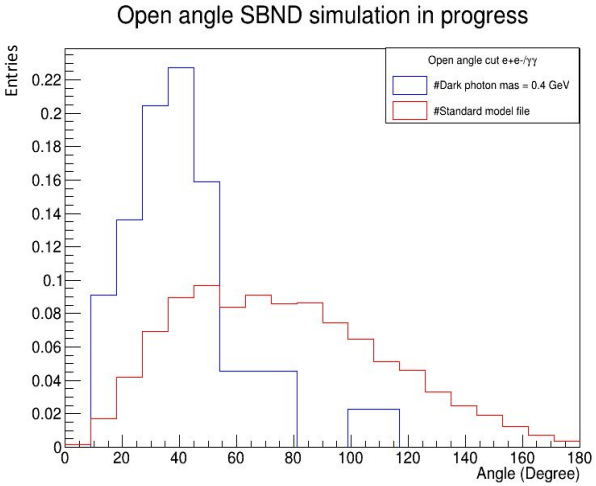

Efficiency dm
Efficiency sm
Energy (GeV)

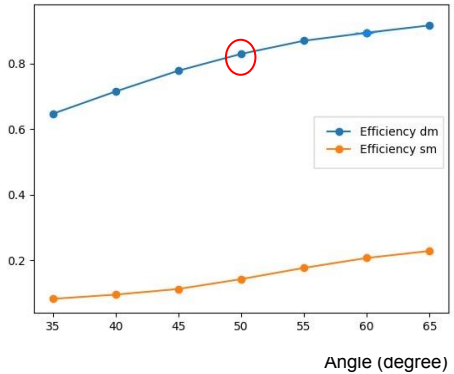

Efficiency dm
Efficiency sm
Energy (GeV)

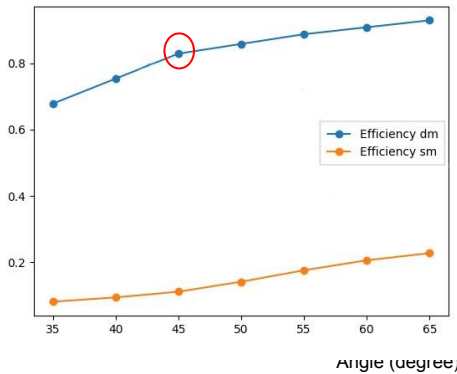

Efficiency dm
Efficiency sm
Energy (GeV)

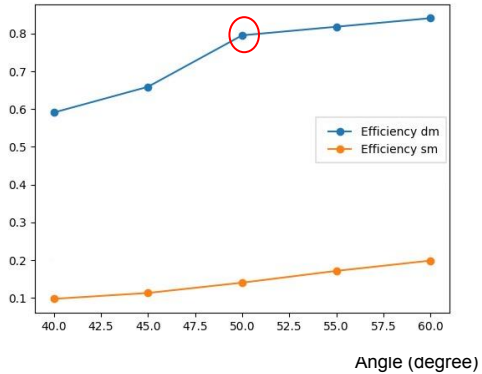

Open angle SBND simulation in progress
Open angle cut e+e-/γγ
#Dark photon mas = 0.2 GeV
#Standard model file
Entries
Angle (Degree)


Open angle SBND simulation in progress
Open angle cut e+e-/γγ
#Dark photon mass = 0.3 GeV
#Standard model file
Entries
Angle (Degree)

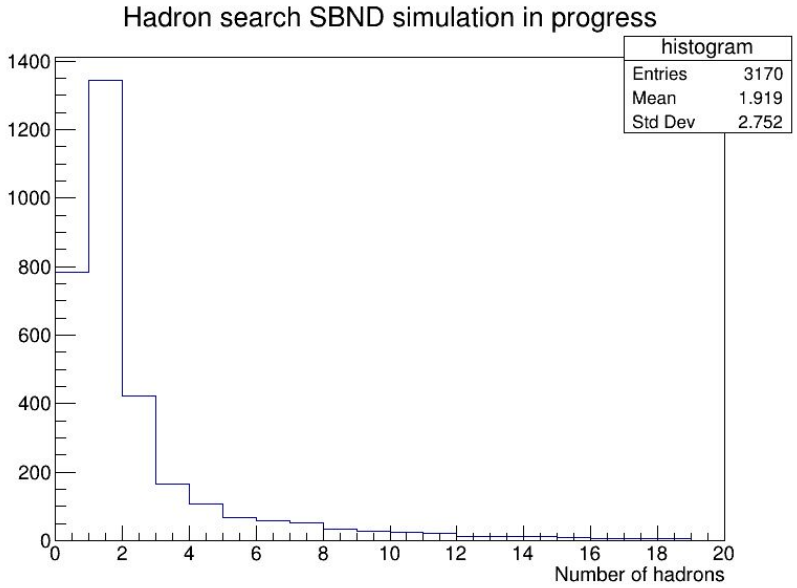

Open angle SBND simulation in progress
Open angle cut e+e-/γγ
#Dark photon mas = 0.4 GeV
#Standard model file
Entries
Angle (Degree)


Efficiency dm
Efficiency sm
Angle (degree)


Efficiency dm
Efficiency sm


Efficiency dm
Efficiency sm
Angle (degree)

# Work in progress




- Cuts combination
- More statistics
- dE/dx
- Invariant mass

# *Thank you for your attention!*