DUNE BSM Group Overviews

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Near Detector Software Workshop

07/24/2019

Motivation

- **Primary physics goal of DUNE : MH, CP Violation**
- ***However, other mechanisms could be responsible for neutrino flavor change on a sub-leading level***
- ***Neutrino physics offers great potential for digging out the physics beyond the standard model (BSM).***
- ***DUNE detector-beam configuration provides an excellent opportunity to study physics beyond standard neutrino oscillations***
- ***LArTPC detector both for Near and Far detector for DUNE will be ideal to probe BSM Physics***

BSM Physics WG Scope and Goals

- ***Enrich DUNE Physics case by studying sensitivities to a wide variety of non Standard Model phenomena***
  - *Looking into both Two-Detector (long-baseline) and ND-only (short-baseline) topics*
  - *Explore high-intensity beam, large FD detector mass, and high resolution of both ND and FD*
  - *Collaborate with Long-Baseline Physics group on topics that may affect standard oscillation measurements*
- ***Develop code framework to carry out these studies and provide tools for others to test new ideas/models***
- ***Inform beamline and/or detector design by reporting how sensitivities are modified by different designs or potential enhancements***

Topics Being Studied

- *Light Sterile Neutrinos*
- *Neutrino Tridents*
- *Low-Mass Dark Matter*
- ν_τ *Physics Opportunities*
- *Non-Standard* ν *Interactions (NSI)*
- *Non-Unitarity and CPT Violation*
- *Inelastic Boosted Dark Maker*
- *Large Extra dimensions*

ND size used for the BSM searches

- ***Overall structure of the DUNE ND considered as LArTPC detector with the following detector dimensions***

ND Properties	Values
Dimensions	7 m wide, 3 m high, and 5 m long
Dimensions of fiducial volume	6 m wide, 2 m high, and 4 m long
Total mass	147 ton
Fiducial mass	67.2 ton
Distance from target	574 m

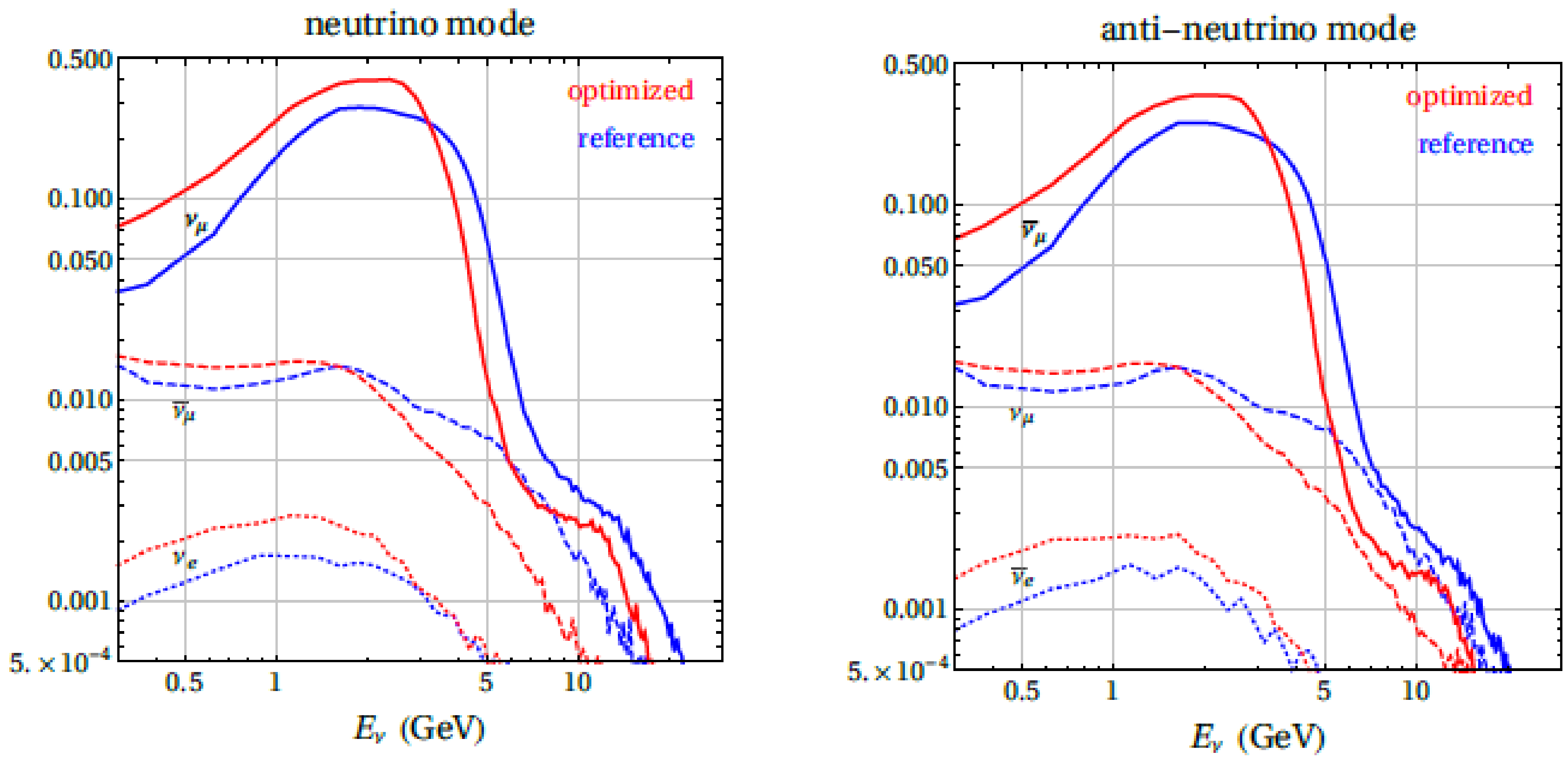
- ***Signal and background efficiencies are different for different physics models.***

- ***The fiducial volume is assumed to include the detector volume up to 50 cm of each face of the detector***

Neutrino Flux

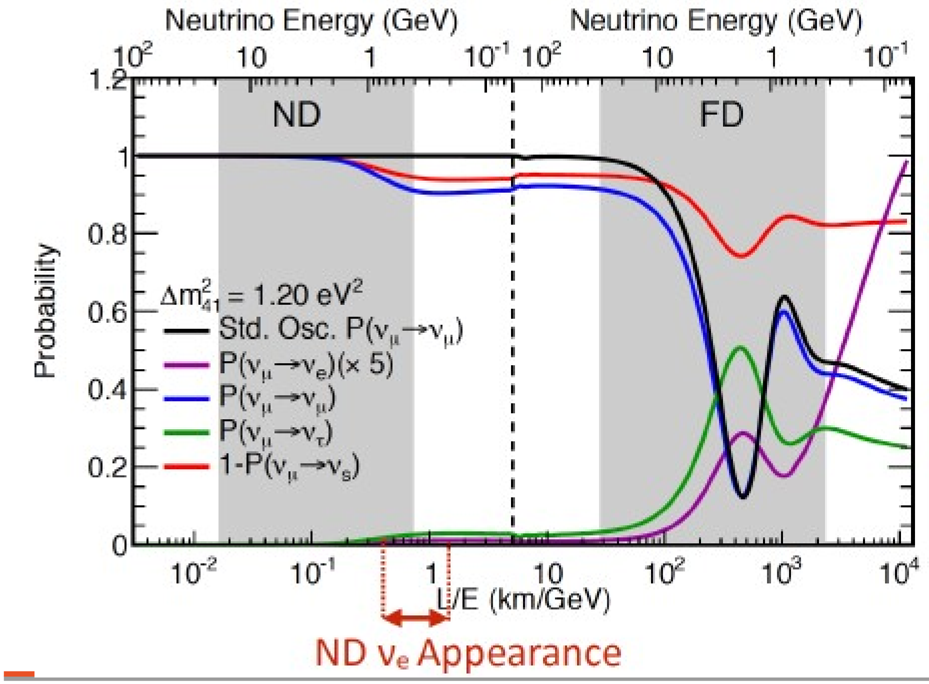
- ***Beam power configuration used for TDR***

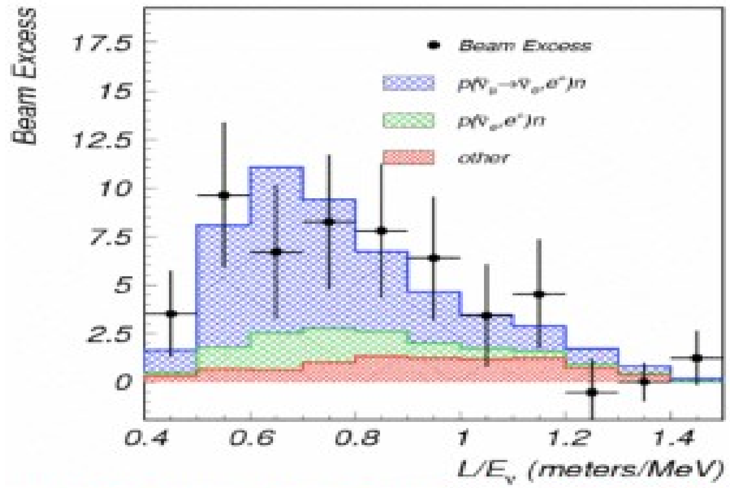
Energy (GeV)	Beam Power (MW)	Uptime Fraction	POT/year
120	1.2	0.56	1.1×10^{21}



Sterile Neutrinos

- *Like the other LBL experiments, DUNE will be able to probe active-to-sterile neutrino mixing.*
  - ***Look for CC and NC disappearance between ND and FD***
  - ***Sensitivity to ν_μ disappearance and ν_e appearance at ND***





LNSD Collab., Phys. Rev. D 64, 112007 (2001)

Work by E. Fernandez-Mar6nez, M. Blennow, S. Rosauro, J. Todd, A.S.

Sterile Neutrino search setup

Source of Uncertainty	MINOS ν_e	T2K ν_e	DUNE ν_e
Beam Flux after N/F extrapolation	0.3%	3.2%	2%
Interaction Model	2.7%	5.3%	$\sim 2\%$
Energy scale (ν_μ)	3.5%	included above	(2%)
Energy scale (ν_e)	2.7%	2.5% includes all FD effects	2%
Fiducial volume	2.4%	1%	1%
Total	5.7%	6.8%	3.6 %
Used in DUNE Sensitivity Calculations			$5\% \oplus 2\%$

Previous Systs. CDR - Table 3.8

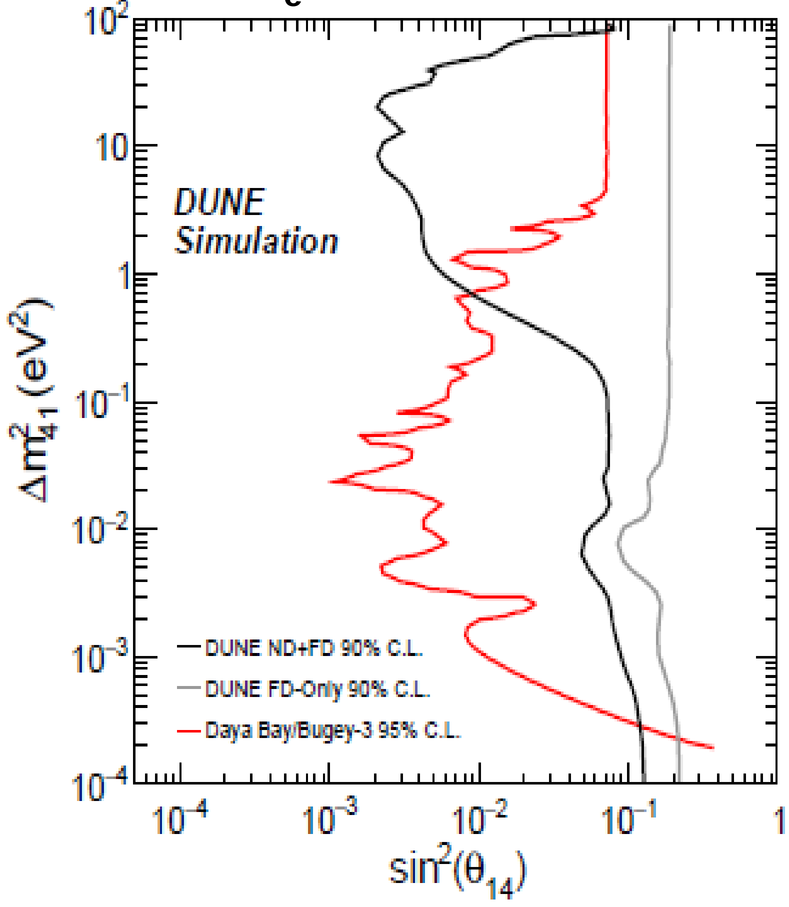
Systematic errors included

- **Signal flux errors (+/-)8%**
- **Background flux error : 15%**
- **F/N flux e : 2%**
- **F/N flux mu : 0.4%**
- **CC x-sec error : 15%**
- **NC x-sec error : 25%**
- **F/N x-sec : 2%**

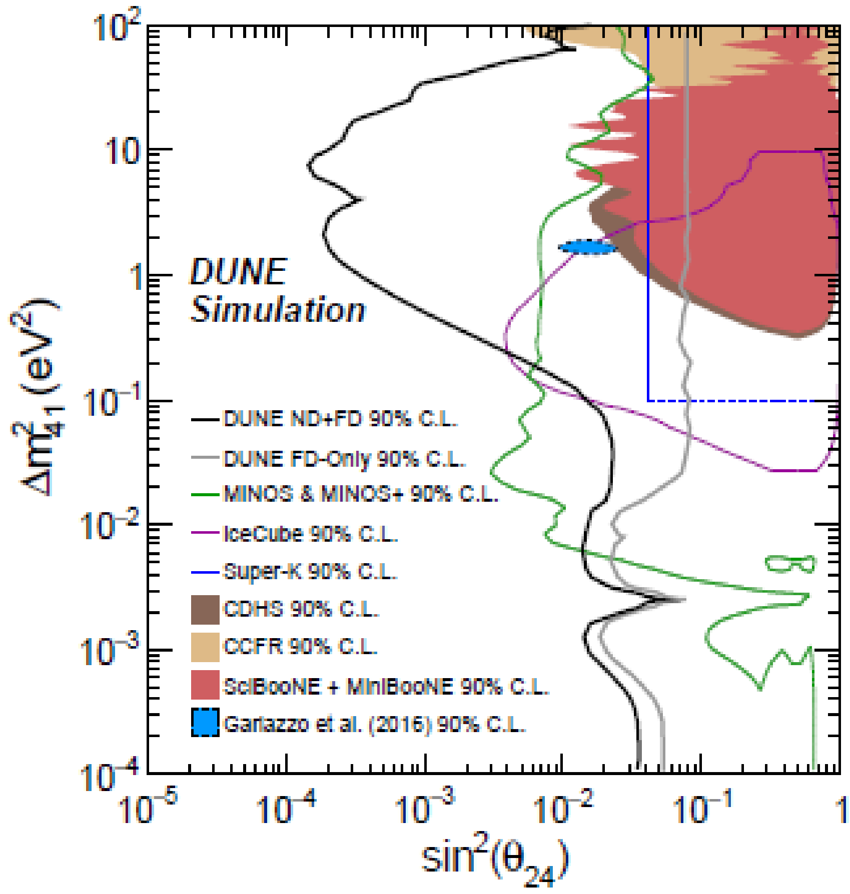
- *GLoBES implementation with simultaneous fit of near and far detector*
- *Using GLoBES plugin for steriles and NSI by J. Kopp. Assuming 3+1 model with one sterile neutrino: ◎hxps://www.mpi-hd.mpg.de/personalhomes/globes/tools/snu-1.0.pdf*
- *120 GeV reference beam, more realistic systematics (significantly larger) with respect to those considered in the CDR*
- *Account for uncertainty in neutrino production point (or pion decay point) between target and ND by applying a 20% energy smearing obtained by integrating gaussian in reco. energy E*

Sterile Neutrino Results

ν_e CC samples

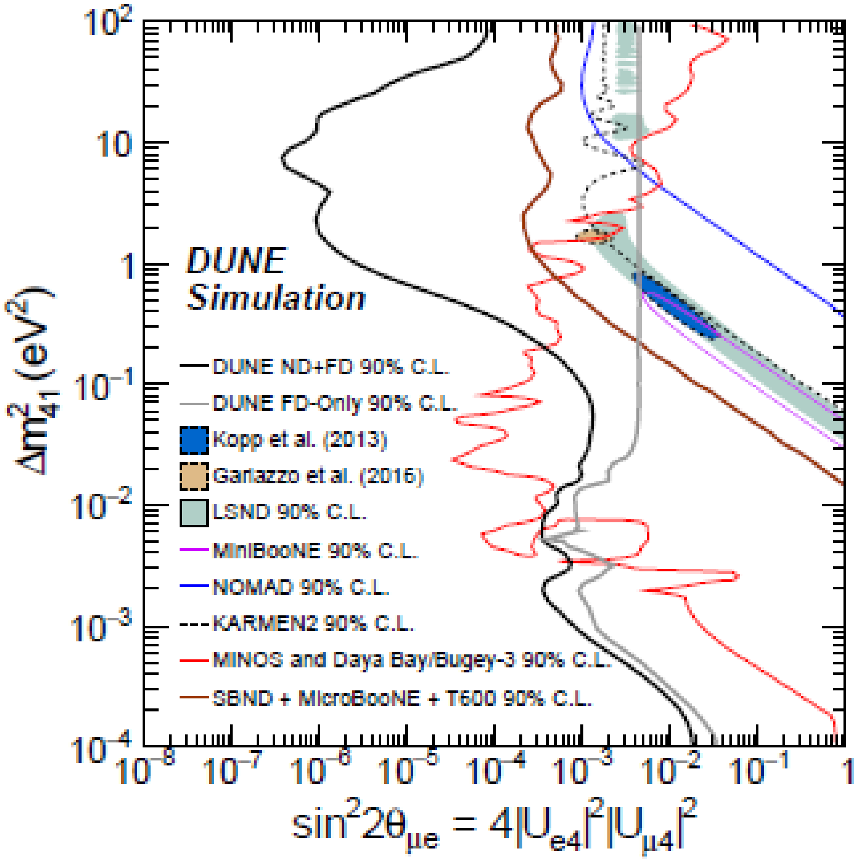


ν_μ CC and NC samples

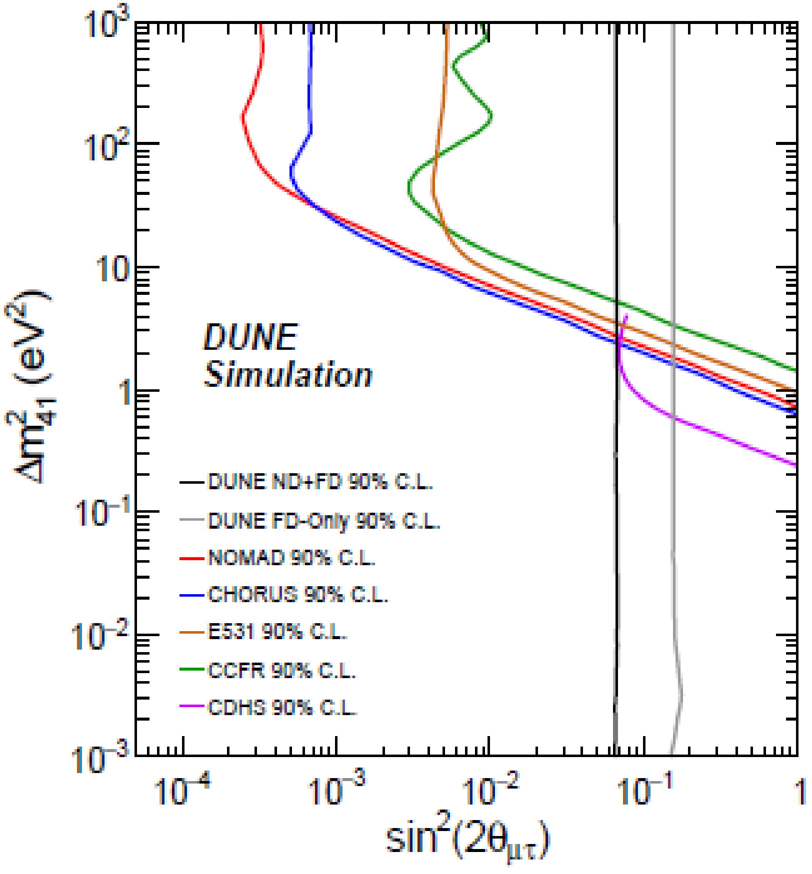


Sterile Neutrino : Result

App + disappearance



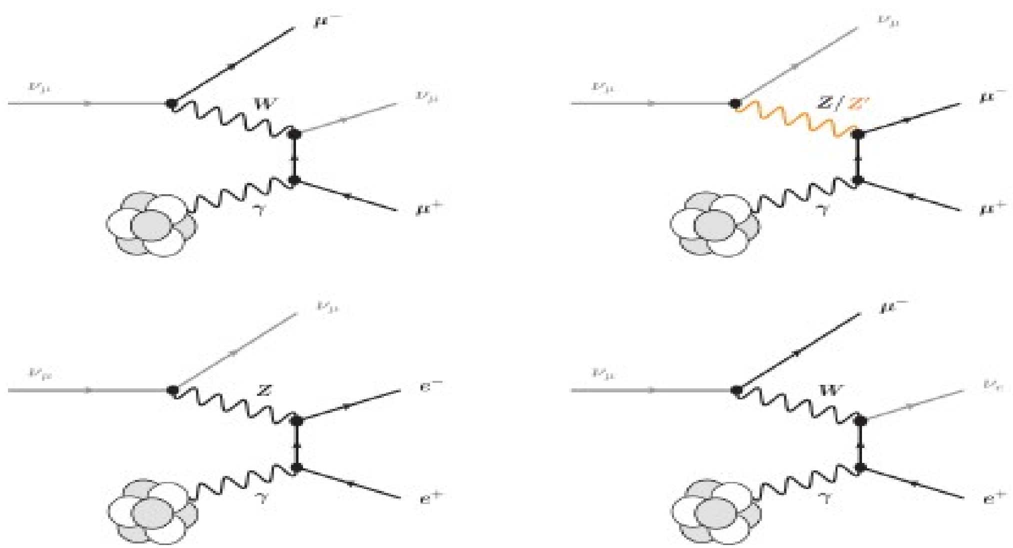
Disappearance in NC sample



Neutrino Tridents in ND

- ***Rare SM process. Has been observed with measured cross section in good agreement with SM***

W. Altmannshofer, S. Gori,
J. Martin-Albo, M. Wallbank, A.S.



$$\frac{\sigma(\nu_\mu \to \nu_\mu \mu^+ \mu^-)_{\rm exp}}{\sigma(\nu_\mu \to \nu_\mu \mu^+ \mu^-)_{\rm SM}} = \begin{cases} 1.58 \pm 0.64 & \text{(CHARM II)} \\ 0.82 \pm 0.28 & \text{(CCFR)} \\ 0.72^{+1.73}_{-0.72} & \text{(NuTeV)} \end{cases}$$

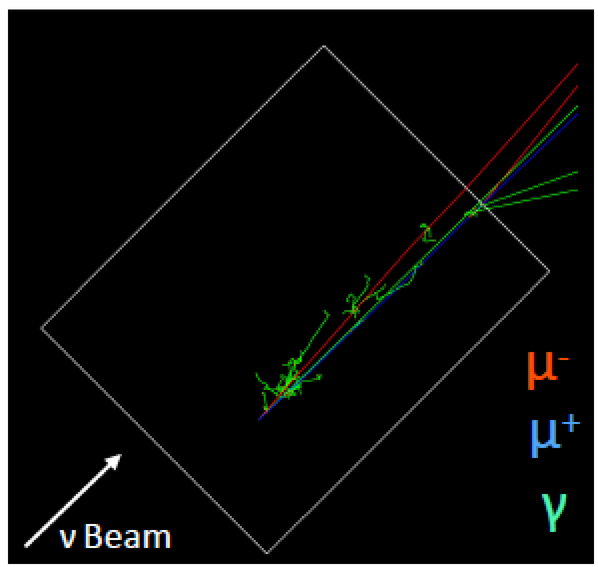
- ***Strong probe of potential new Z' boson advanced as explanation for (g-2) anomaly***

→ *Z' couples to muons, but also to muon neutrinos. Enhances trident production w.r.t. SM*

→ *DUNE can probe still-allowed m Z' < 0.4 GeV region*

Trident setup

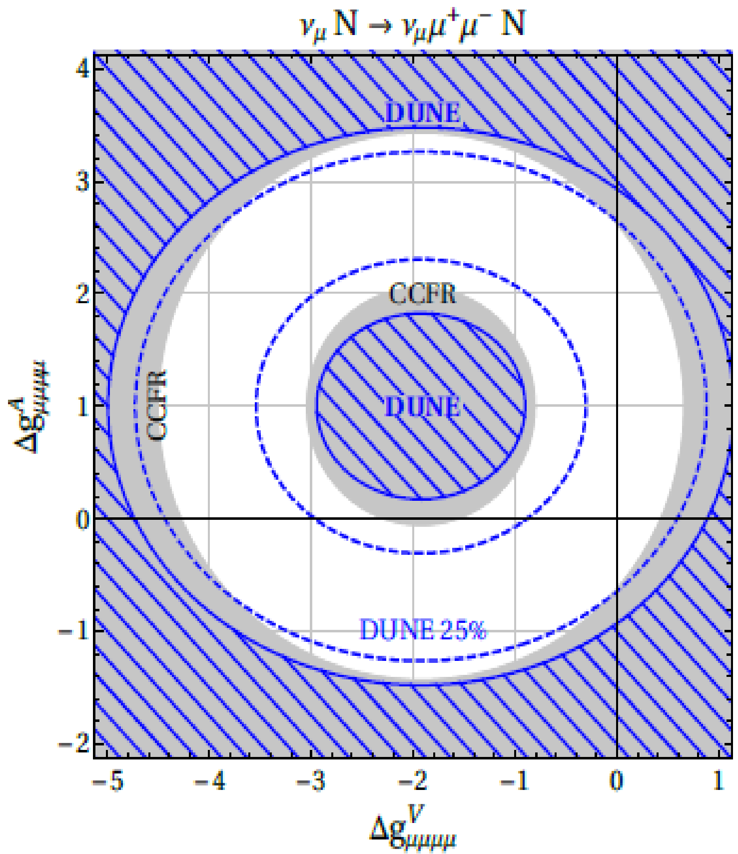
- ***New MC event generator of neutrino trident events (in argon or iron) written.
Code publicly available***
- ***Backgrounds (CC interac6ons in ND LArTPC) generated using GENIE neutrino generator***
- ***Signal and backgrounds run through simulation of the DUNE ND***
- ***Event selection for neutrino tridents developed***

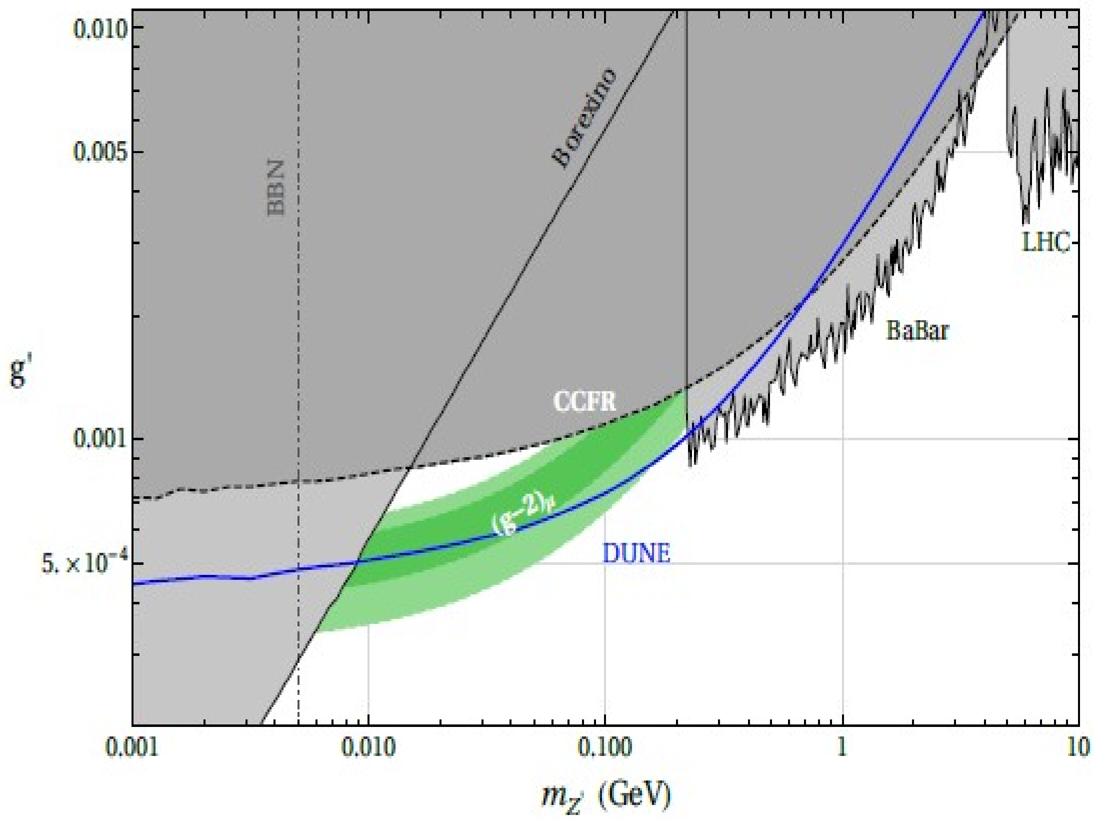


	Coherent	Incoherent
$\nu_\mu \to \nu_\mu\ \mu^+\mu^-$	1.17 ± 0.07 (516 ± 31)	0.49 ± 0.15 (216 ± 66)
$\nu_\mu \to \nu_\mu\ e^+e^-$	2.84 ± 0.17 (1252 ± 75)	0.18 ± 0.06 (79 ± 27)
$\nu_\mu \to \nu_e\ e^+\mu^-$	9.8 ± 0.6 (4322 ± 265)	1.2 ± 0.4 (529 ± 176)
$\nu_\mu \to \nu_e\ \mu^+e^-$	0 (0)	0 (0)
$\bar{\nu}_\mu \to \bar{\nu}_\mu\ \mu^+\mu^-$	0.72 ± 0.04 (318 ± 18)	0.32 ± 0.10 (141 ± 44)
$\bar{\nu}_\mu \to \bar{\nu}_\mu\ e^+e^-$	2.21 ± 0.13 (975 ± 57)	0.13 ± 0.04 (57 ± 18)
$\bar{\nu}_\mu \to \bar{\nu}_e\ e^+\mu^-$	0 (0)	0 (0)
$\bar{\nu}_\mu \to \bar{\nu}_e\ \mu^+e^-$	7.0 ± 0.4 (3087 ± 176)	0.9 ± 0.3 (397 ± 132)

Event rates per year (1.1E21) and tonne of argon

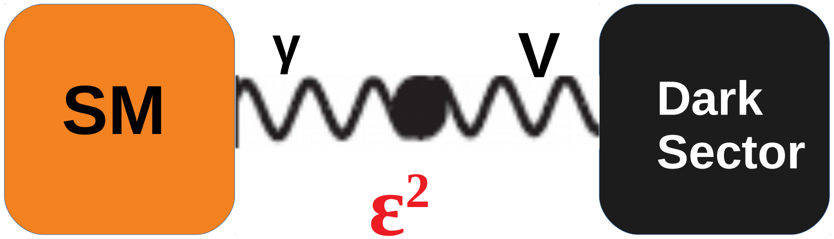
Results: Neutrino Trident





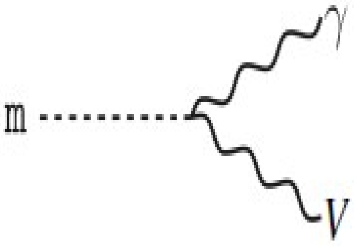
Low mass dark matter search at ND

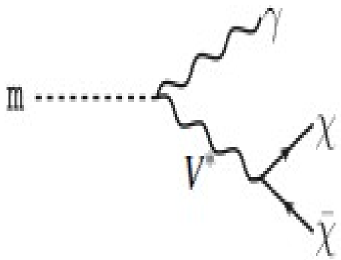
- ***Models of sub-GeV dark matter typically involve scalar or fermion DM and vector or scalar mediators***
- ***Maybe the simplest model is known as the "dark photon" model. The mediator is a new gauge field which "mixes" with the SM photon through ε***



- **Dark Matter production :**

Meson decay is the dominant channel for mediator < 2 GeV (sub-GeV)

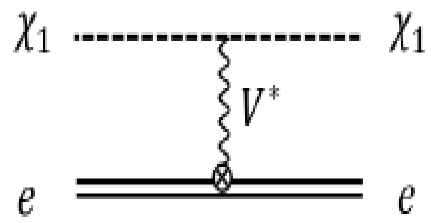




Work by A.C, K.K, P.M., V.V, J.Yu

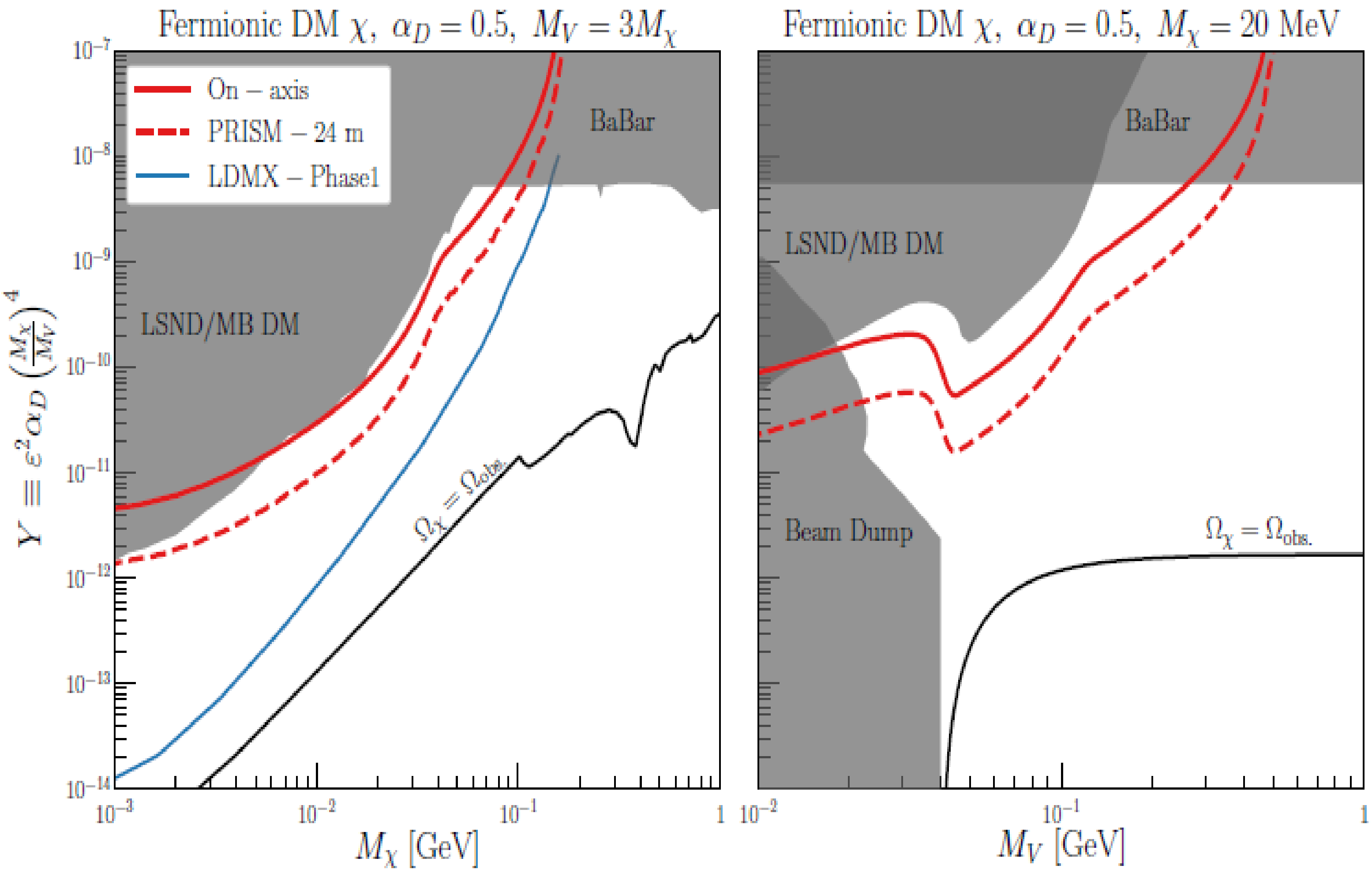
Detection of DM and ND setup

- ***Interactions look like just neutrino interactions***
- All interactions are neutral current (since mediator is not charged)
- **In this analysis we consider only Electron Elastic scattering**



- ND fiducial volume is same as other studies
- ***Background process includes any process with electron recoil (ν_μ -e, and ν_e CCQE interaction)***
- 3.5 years of data (both neutrino and anti-neutrino mode) used for the analysis with 1.1E21 POT

Results



Fermionic DM χ, $\alpha_D = 0.5$, $M_V = 3M_\chi$
On – axis
PRISM – 24 m
LDMX – Phase1
BaBar
LSND/MB DM
$\Omega_\chi = \Omega_{obs}$
$Y \equiv \epsilon^2 \alpha_D \left(\frac{M_\chi}{M_V}\right)^4$
M_χ [GeV]
Fermionic DM χ, $\alpha_D = 0.5$, $M_\chi = 20$ MeV
BaBar
LSND/MB DM
Beam Dump
$\Omega_\chi = \Omega_{obs.}$
M_V [GeV]

Summary of Needs for BSM group

- **Near term:**

  - ***Description of the ND structure, dimensions, fiducial volume***
  - ***Response function for different particles (muon, electron)***
  - ***Realistic number about the detector systematics***
  - ***Possibilities of having off-axis detector***

- **Long term:**

  → ***Full reconstruction with DUNE-ND simulation setup***
  → ***Integration of different MC generator within DUNE-ND setup***
  → ***Detail understanding about the particle identification and reconstruction***

Summary of Needs for BSM group

- ***We are preparing requirement list same as LBL group***
- *Each analysis group will identify the requirement to perform more realistic analysis*

ND requirements | BSM: Tridents

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	A	B	C	D	E	F
1		NAME	SUBSYSTEM	LABEL	PRIMARY TEXT	VALUE
2		Descriptive name of specification	Which subsystem does this apply to (LAr, MPD, 3DST-S, DUNE-PRISM)		Text of requirement/specification	Specification Valu (Number + units)
3	OVERARCHING REQUIREMENTS					
4	O0	Measure the rate of neutrino trident interactions in the LAr.	LAr, MPD		Want this to be as precise as possible. The measurement will likely be dominated by statistical errors.	
5						
6	CAPABILITIES					
7	C1	High tracking efficiency with LAr detector	LAr			
8	C2					
9	C3					
	C4					

- **We are expecting to have the table within few weeks**

Conclusions

- *BSM Physics searches with DUNE are an active area of research within theory/ phenomenology community and also within the DUNE collaboration*
- *Excellent space for development of collaborations between theorists/ phenomenologists and experimentalists.*
- *Results are in place for TDR with identical ND fiducial volume, neutrino flux and POT*
- *Different physics model uses different MC generator*
- *Require common simulation framework along DUNE-ND group and integrate different MC generator*
- *Full reconstruction of events within the DUNE-ND frame-work will be the final goal.*

Thank You