

Hunting for Light Dark Matter

WITH THE

NOvA DETECTOR

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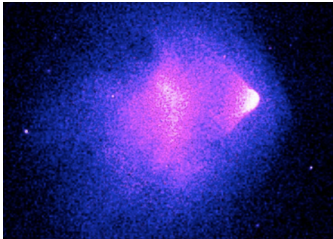
(for NOvA collaboration)



14th of January, NDM-2020, Hurghada



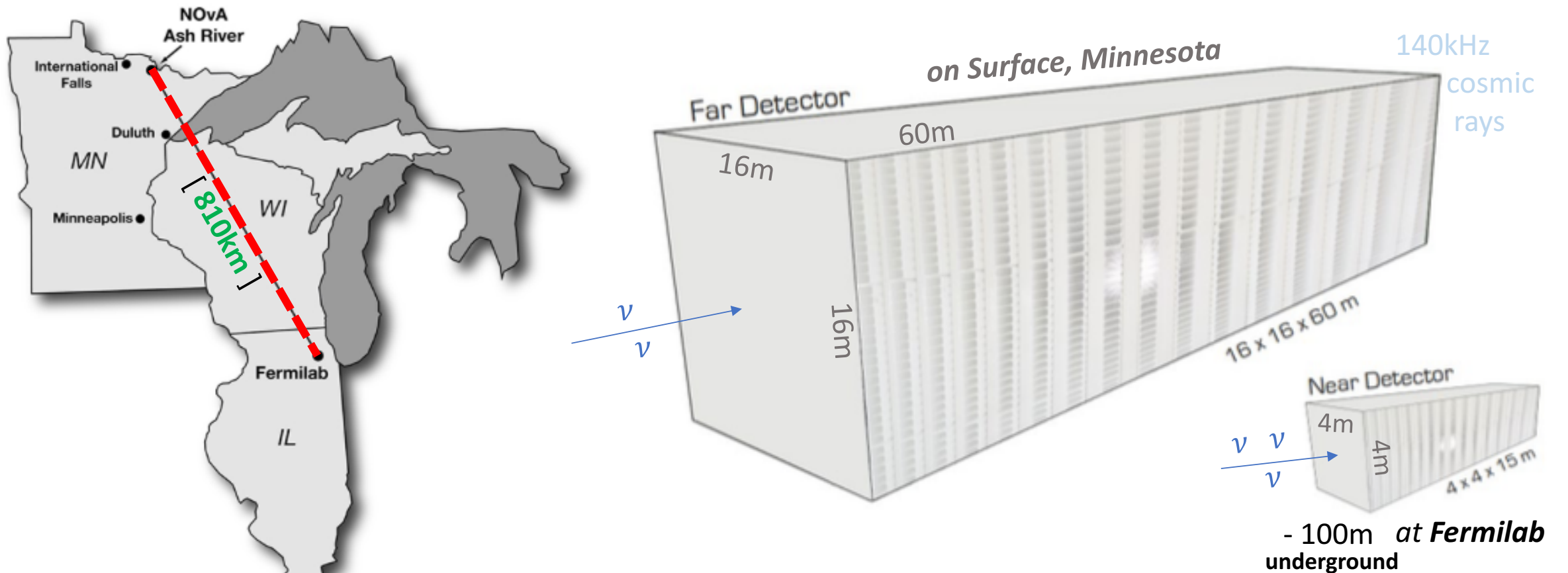
Dark Matter (DM) Indications

- Anomalous Visible Matter Rotation: F. Zwicky 1933 (Coma Cluster)
V.C. Rubin 1978 (Galaxies)
- Gravitational Lensing of Light: A. Einstein 1936, Zwicky 1937
- Galaxy Cluster Collisions: **Bullet Cluster** (8σ , 2006)  Chandra X-ray
- Cosmology: **Planck 2014: CMB spectrum:** $\Omega_{DM} / \Omega_b \approx 5/1$

Direct detection of Dark Matter is Ultimate Goal of Experimental Physics

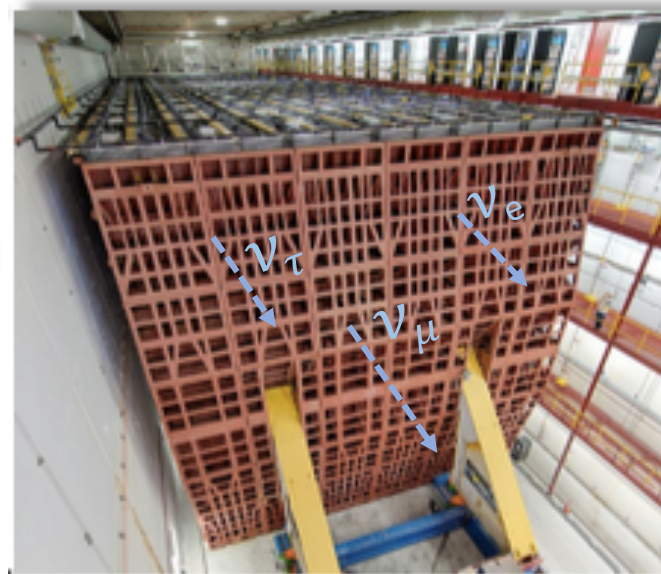
NOvA Experiment

- 810km Long-Baseline Neutrino Oscillation ($\nu_\mu \rightsquigarrow \nu_e$).

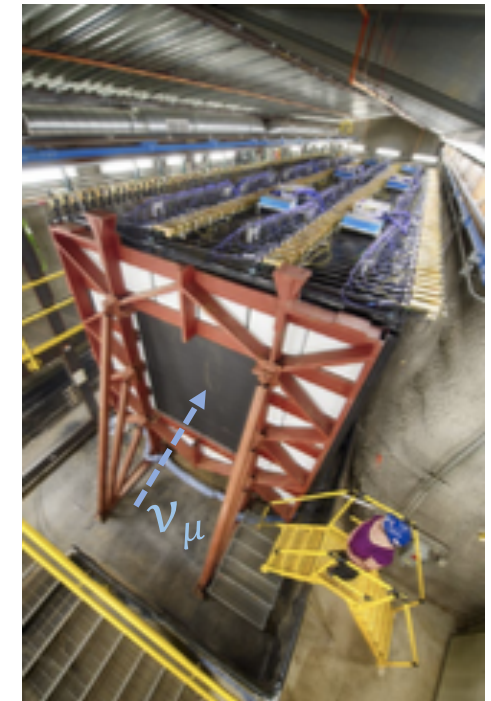


NOvA Experiment

- 810km Long-Baseline Neutrino Oscillation ($\bar{\nu}_\mu \rightsquigarrow \bar{\nu}_e$)



FAR detector: 60m Long, 16m high
 14000 tons, Liquid scintillator (oil)
 344064 pixels, 10752 APDs
 APD sensors: cooled to -15°C



NEAR detector: 16m
 identical functionality
 20192 pixels, 631 APDs
 300 tons

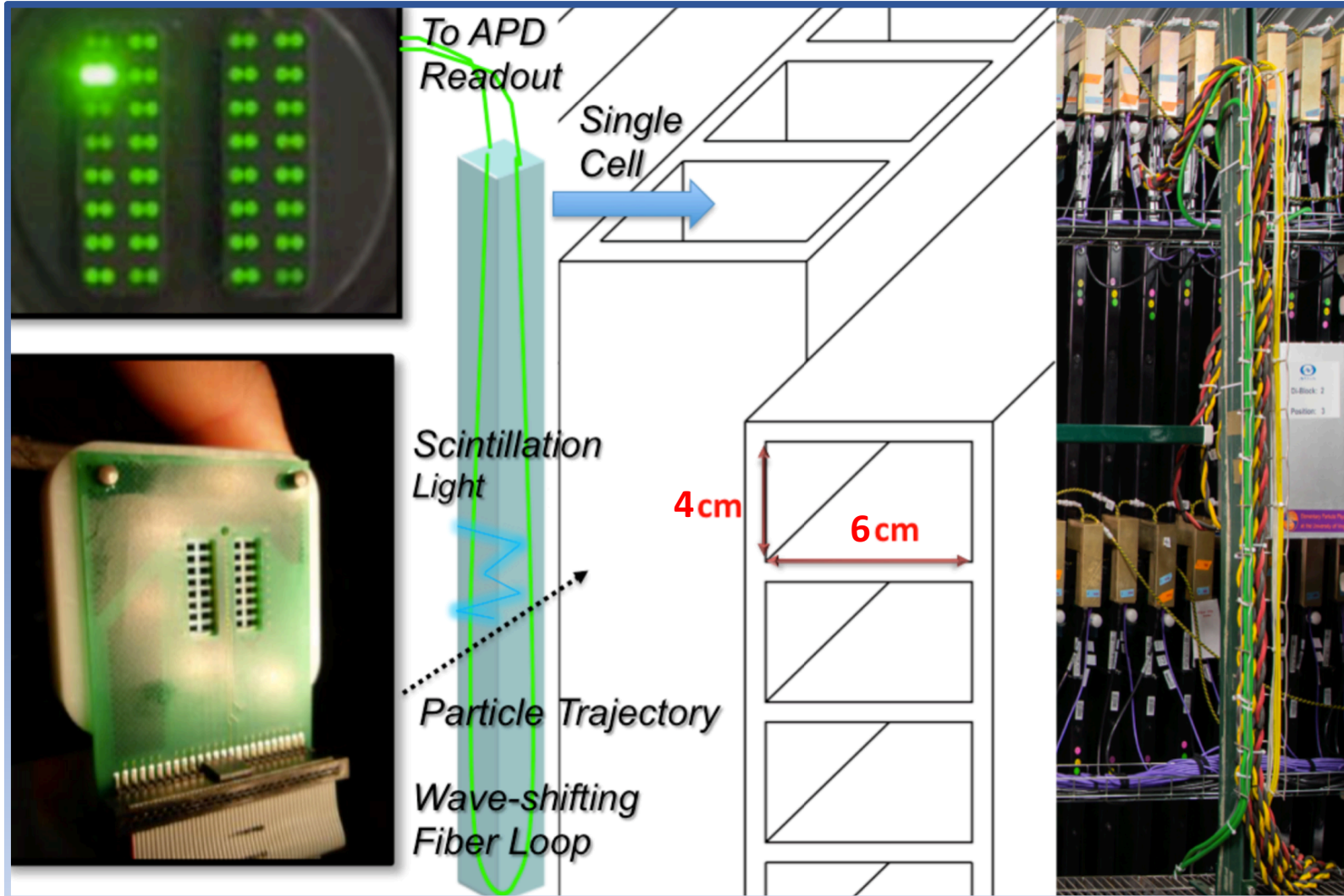
-100m underground

NOvA Detector

1 pixel
 1 Fiber → 2 ends
 32 Fibers → 1 APD

Avalanche
 PhotoDiodes

APDs cooled by
 Peltier Modules
 to $T = -15^{\circ}\text{C}$



Front-End-Boards
GPS synchronized
 (Far + Near detector)

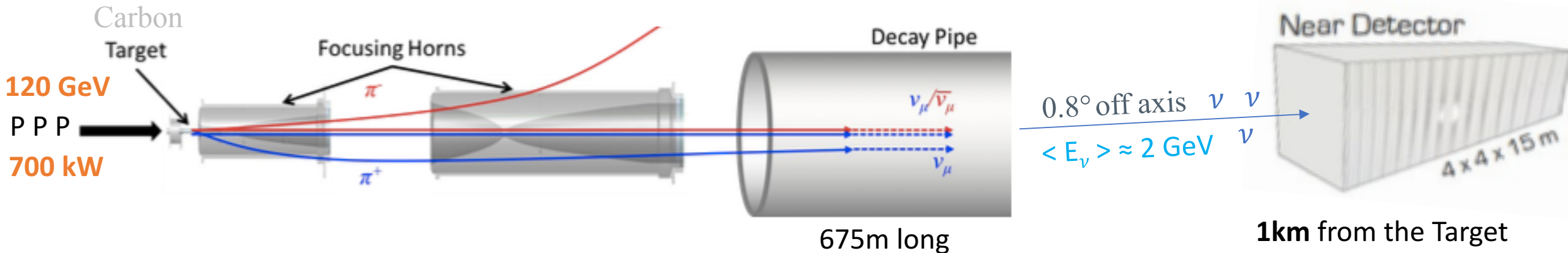
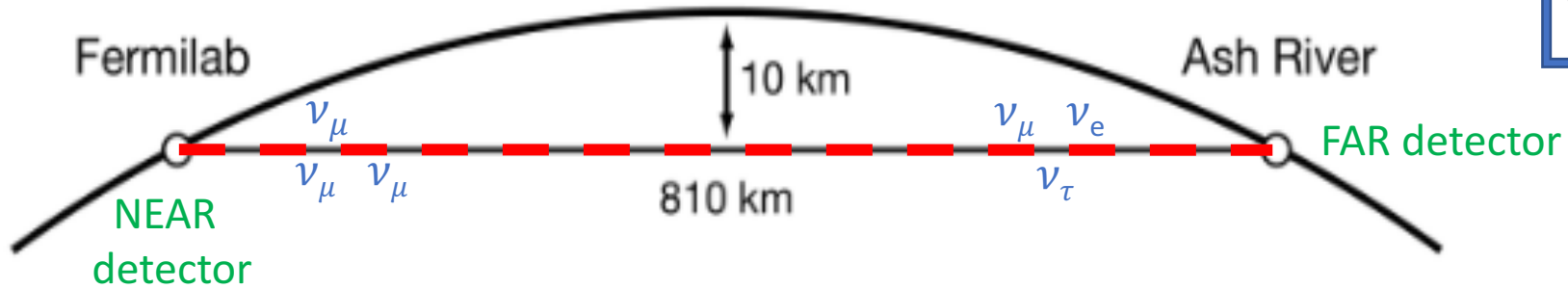
≈ **20 minutes** of DATA
 stored in Memory
 (buffer PC Nodes)
 for Trigger decisions

45sec of continuous
 data can be saved to
 permanent storage
 upon "SN" Trigger

NOvA Experiment

- 810km Long-Baseline Neutrino Oscillation

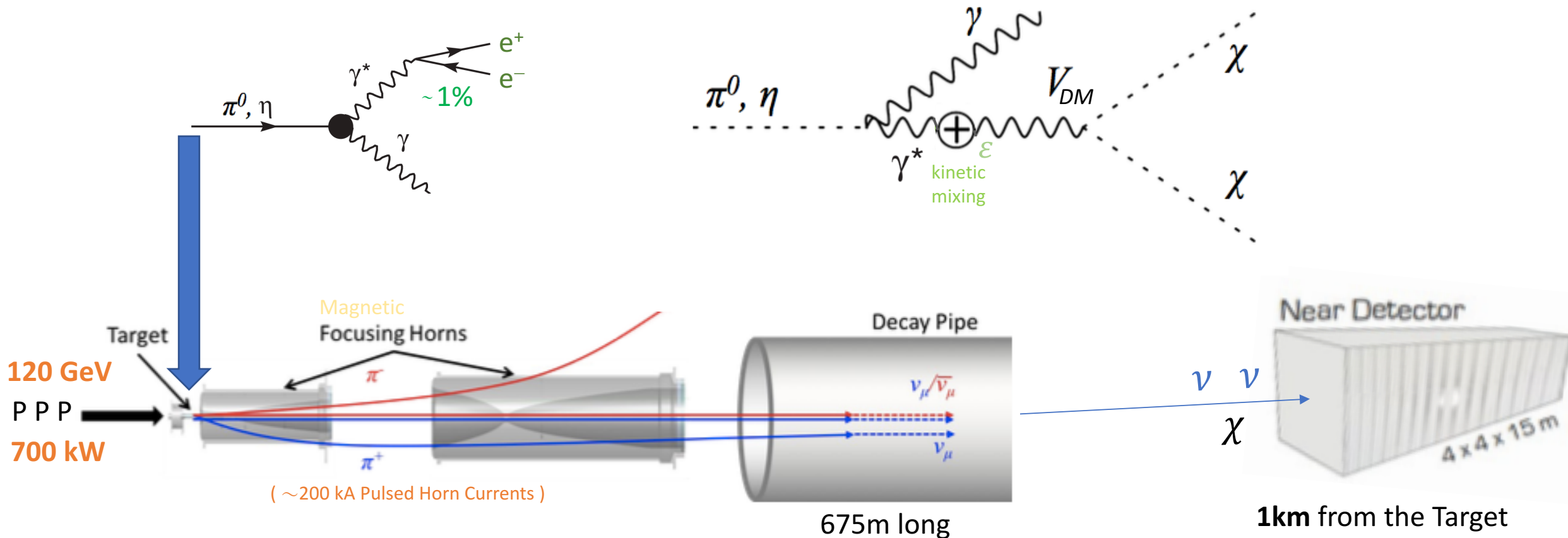
$$\begin{matrix} (\nu_\mu \rightsquigarrow \nu_e) \\ (\bar{\nu}_\mu \rightsquigarrow \bar{\nu}_e) \end{matrix} \text{CP violation}$$



DM at NOvA Experiment

- Dark Matter [$V_{DM} \rightsquigarrow \chi\chi$] production via Vector Portal

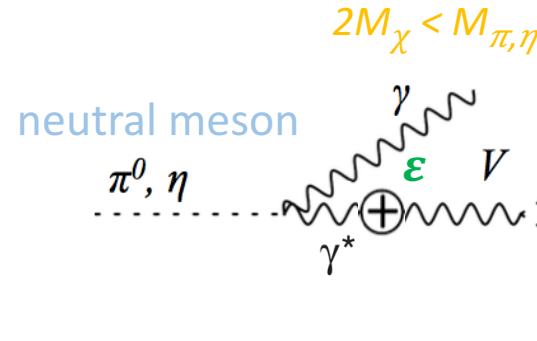
EXAMPLE



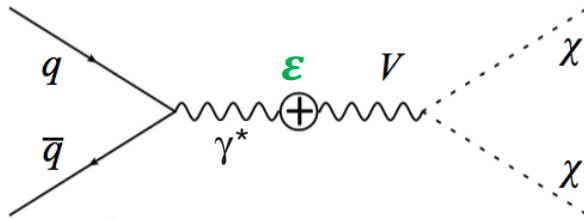
DARK Matter Search in NOvA-Near detector

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

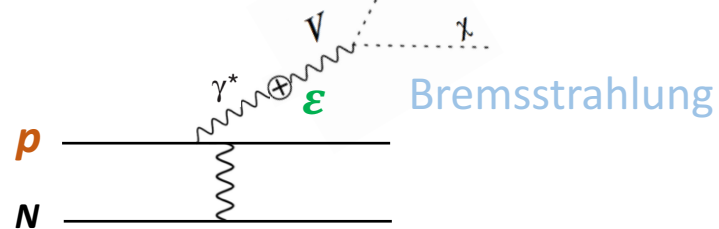
dark photon mixing with virtual gamma



Drell-Yan

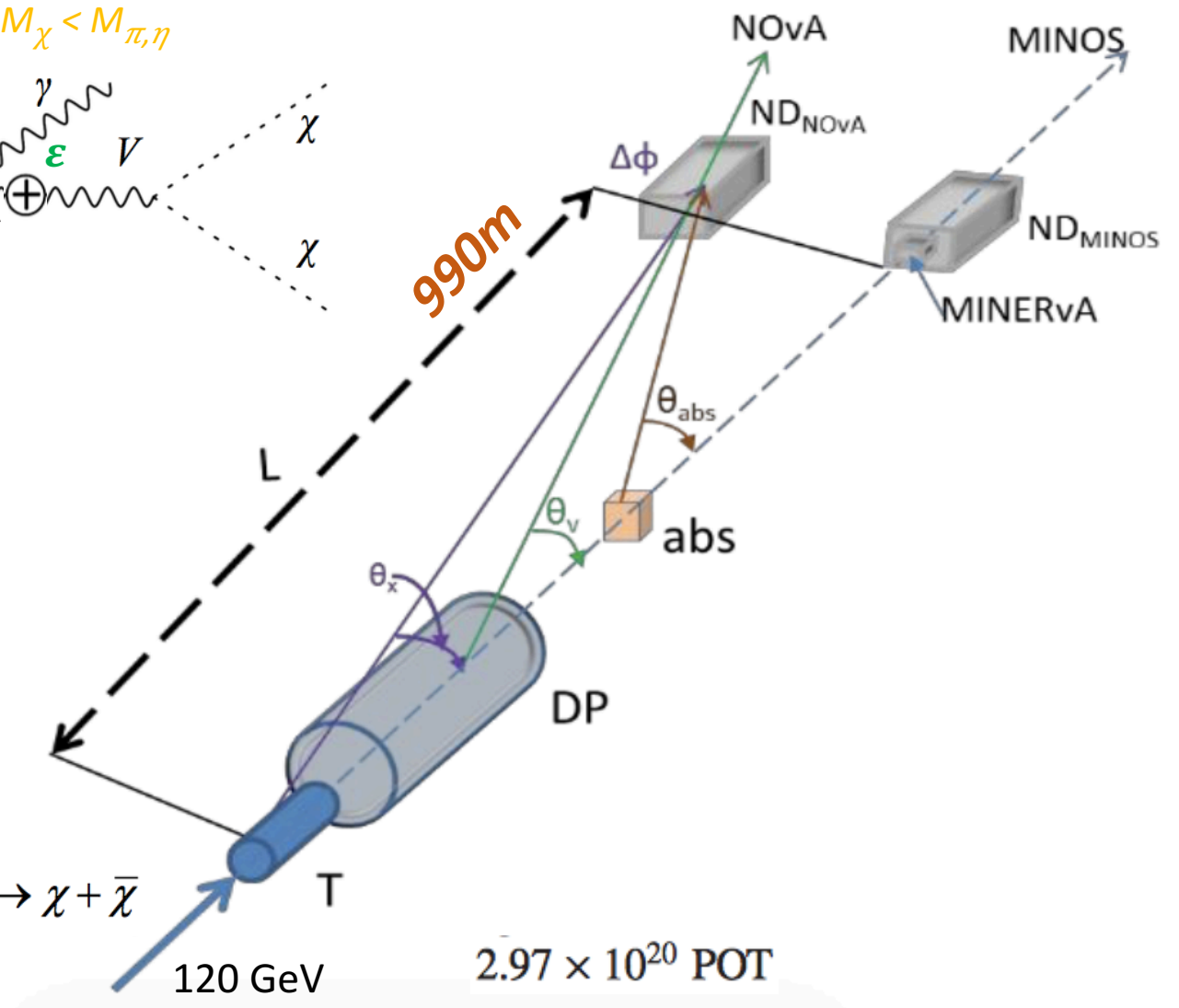


$$2M_{\chi} > M_{\pi,\eta}$$

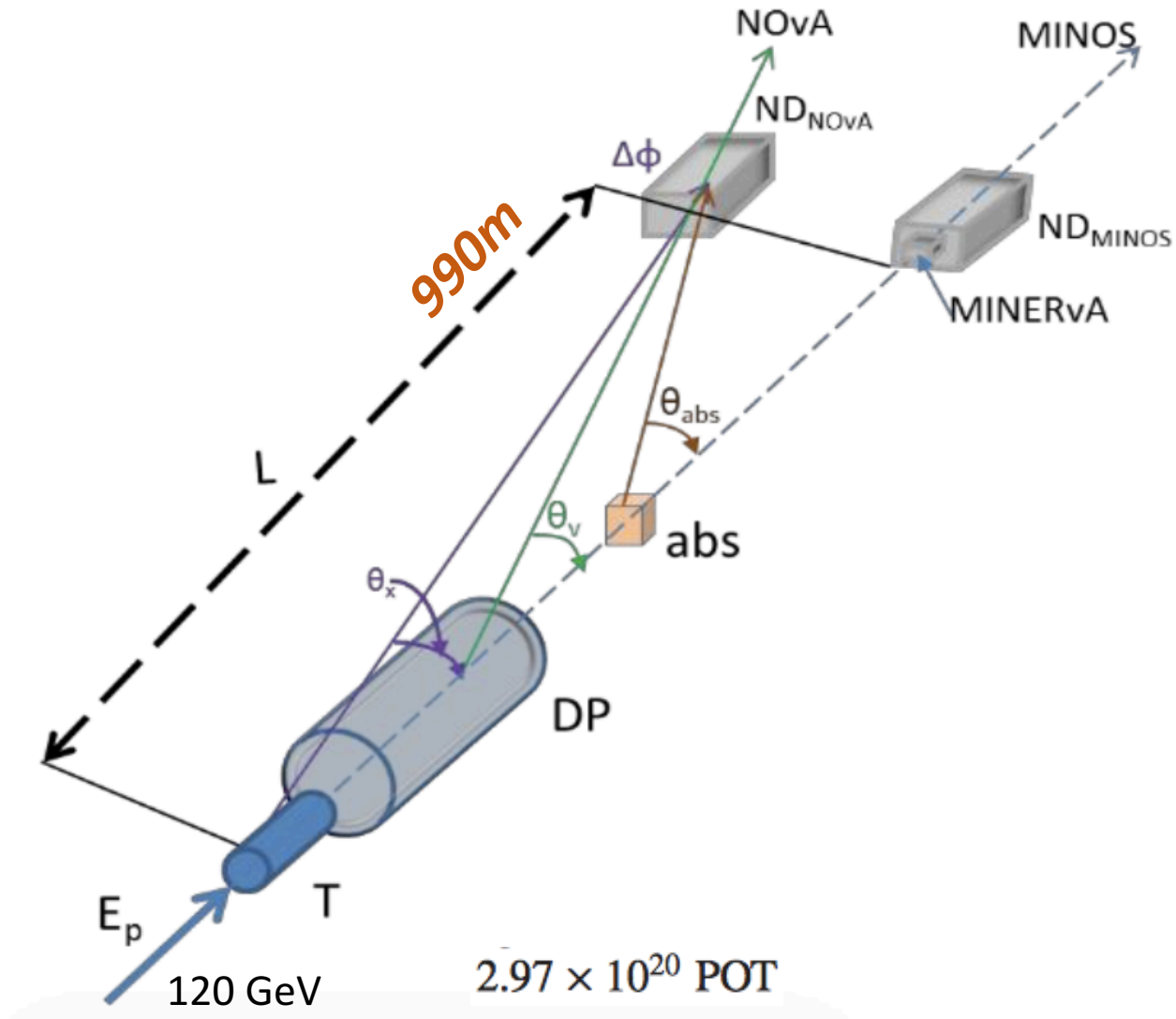


PRODUCTION

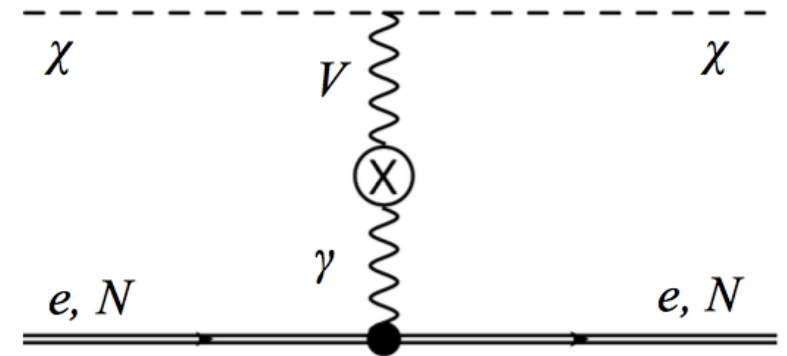
$$p + p \rightarrow V_{DM} \rightarrow \chi + \bar{\chi}$$



DARK Matter Search in NOvA-Near detector



DETECTION



ELASTIC interaction: electrons (nucleons)

[dark photon mass]

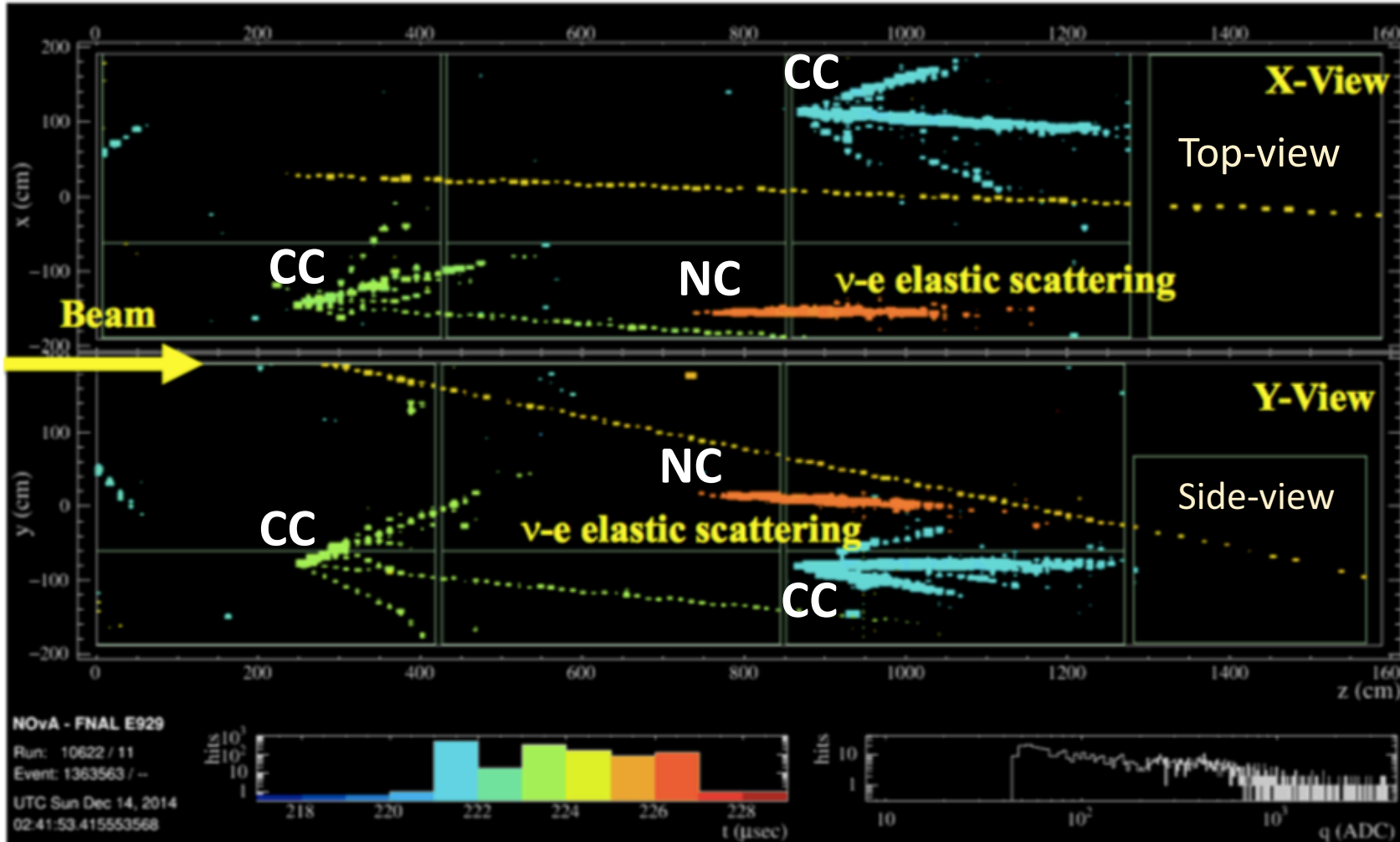
Dark mediator: $M_{DP} \approx 60-1000 \text{ MeV}$

Kinetic mixing: $\epsilon \approx 10^{-3} - 10^{-4}$

DM coupling to V_{DM} : $\alpha_D \approx 0.5 - 0.05$

DM particles mass: $M_\chi \approx 20-300 \text{ MeV}$

NOvA Near Detector (interactions)



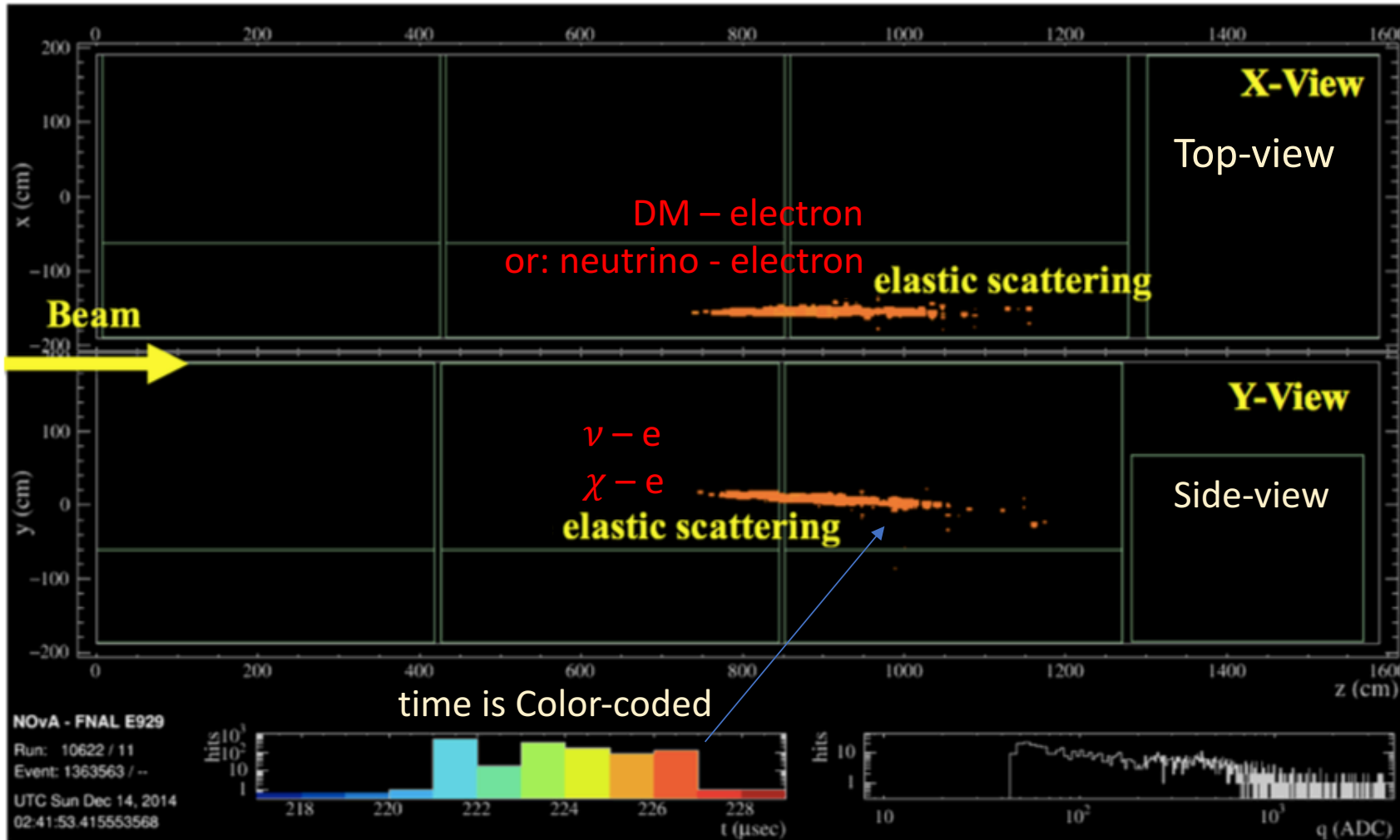
CC and NC elastic $[\nu_\mu]$ interactions in Near Detector (NuMI ν_μ Beam)

Muon neutrino cross sections

nucleons
 $\sigma(\nu, N) \approx 10^{-38} \left(\frac{E_\nu}{\text{GeV}} \right) \text{cm}^{-2}$
 CC

electrons
 $\sigma(\nu, e) \approx 10^{-42} \left(\frac{E_\nu}{\text{GeV}} \right) \text{cm}^{-2}$
 elastic

MC simulation Event, arXiv: 1710.03428, (APS DPF 2017), July 31-August 4, [C17-07-31](#)



DM and Neutrino elastic interactions with **Electrons** in NOvA

Elastic Scattering cross sections:

neutrinos

$$\sigma(\nu, e) \approx 10^{-42} \left(\frac{E_\nu}{\text{GeV}} \right) \text{cm}^{-2}$$

DM

$$\sigma(\chi, e) \approx 10^{-27} \alpha_D \epsilon^2 \left(\frac{100 \text{MeV}}{M_{DP}} \right)^2 \text{cm}^{-2}$$

 10^{-4}
 ↓
 dark photon
 mass $\approx 60 \text{MeV}$

see: Phys.Rev.D99 (2019) 051701.

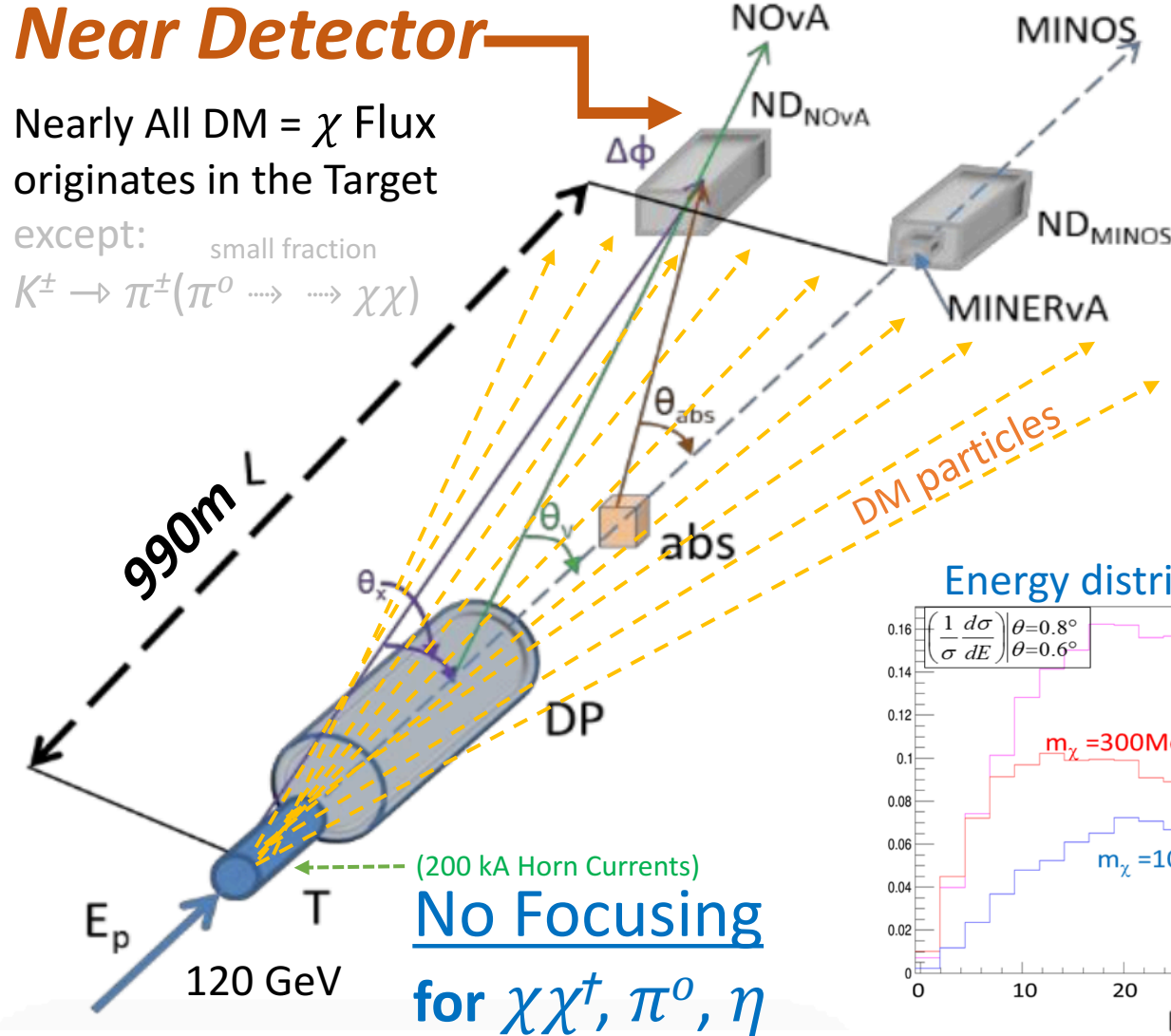
MC simulation Event, arXiv: 1710.03428, (APS DPF 2017), July 31-August 4, [C17-07-31](#)

DARK Matter Flux in NOvA-ND Detector

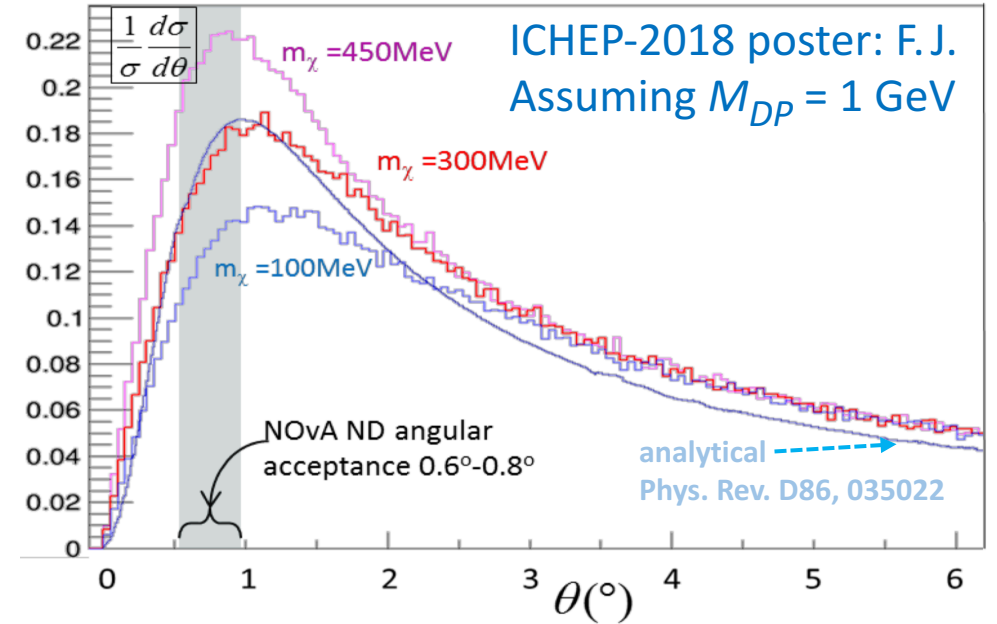
Near Detector

Nearly All DM = χ Flux originates in the Target except:

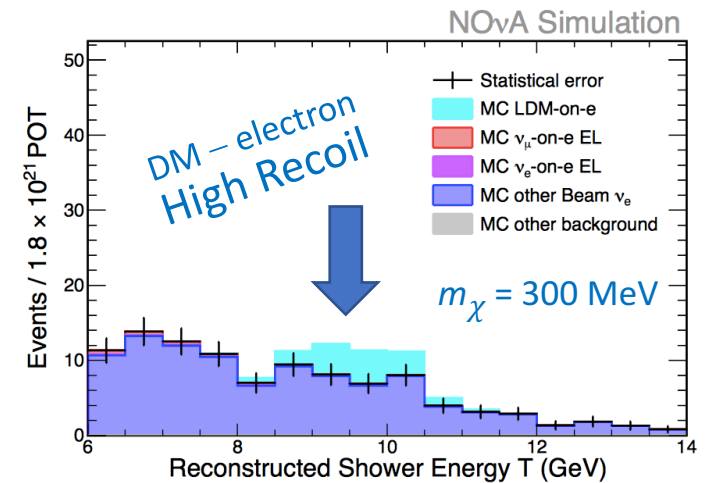
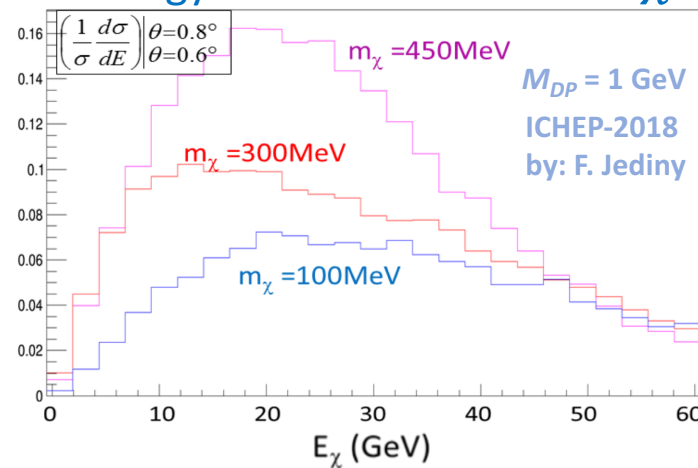
small fraction
 $K^\pm \rightarrow \pi^\pm (\pi^0 \rightarrow \chi\chi)$



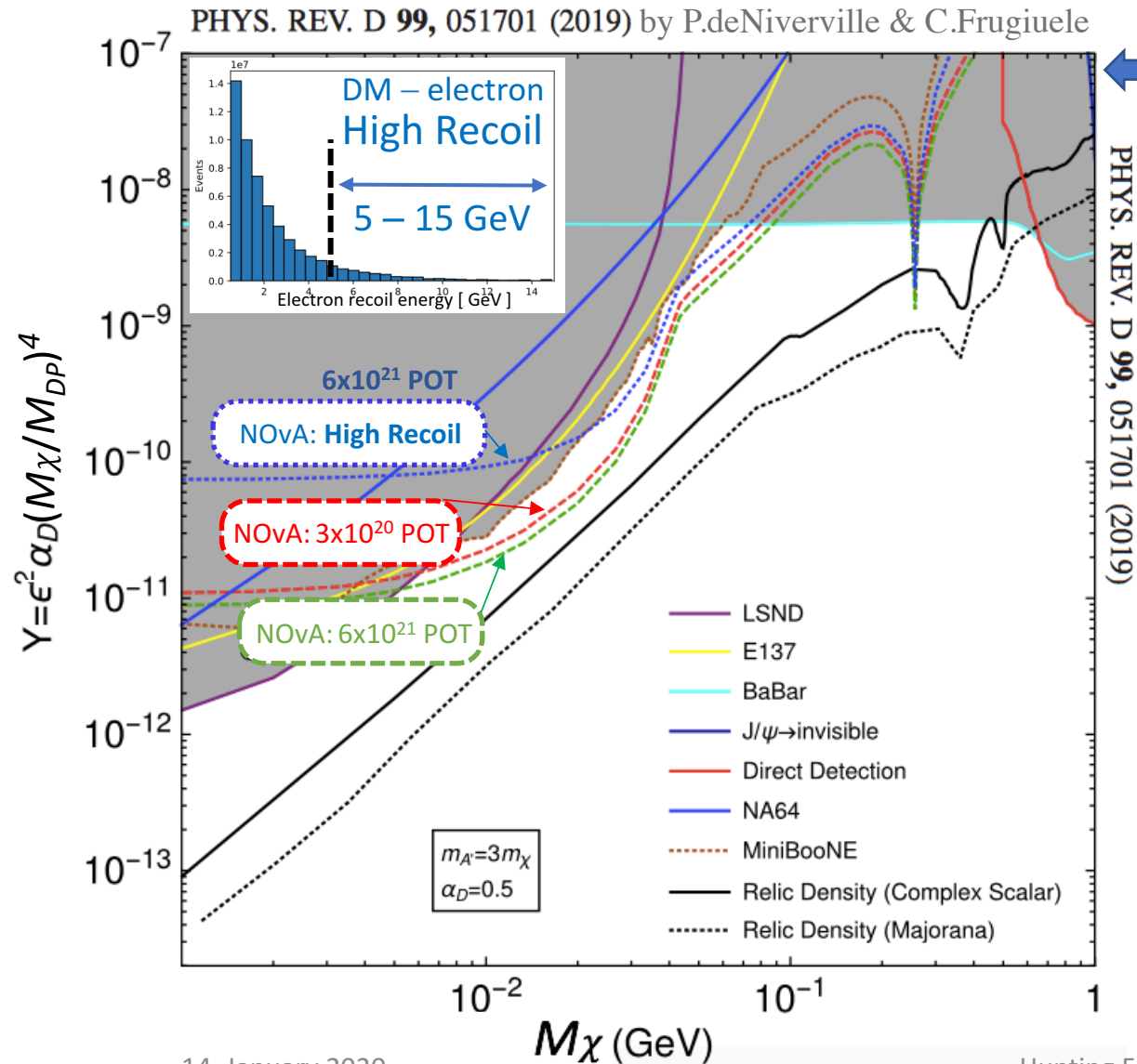
No Focusing
 for $\chi\chi^+, \pi^0, \eta$



Energy distribution for DM = χ

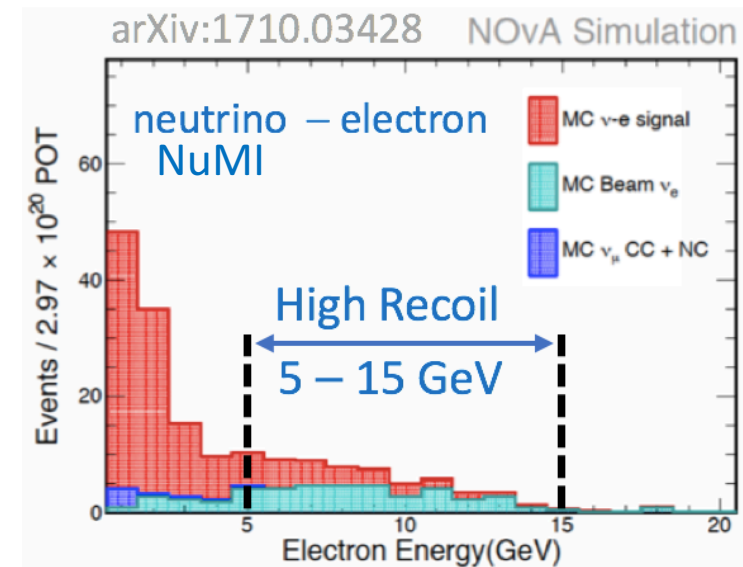


Expected LDM Upper Limits from NOvA-ND detector



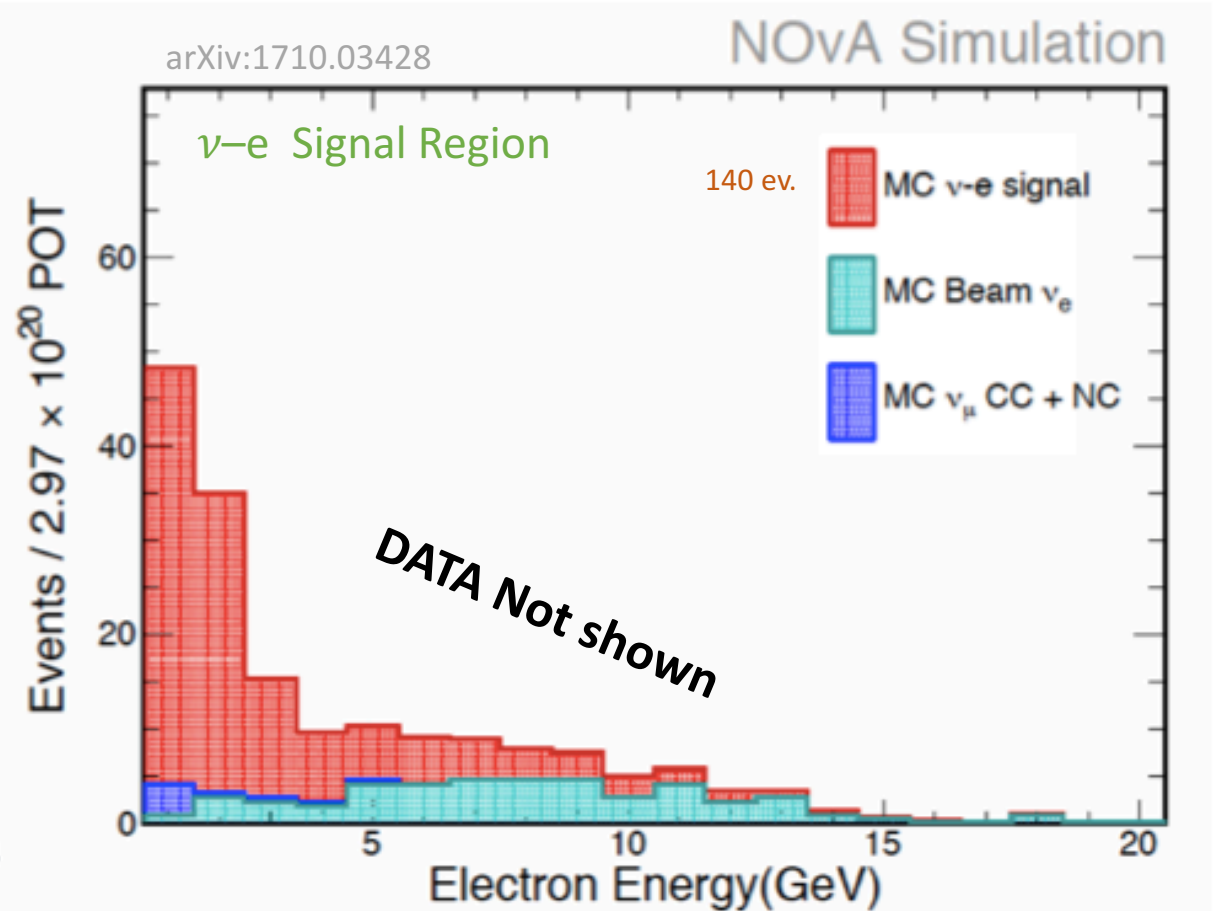
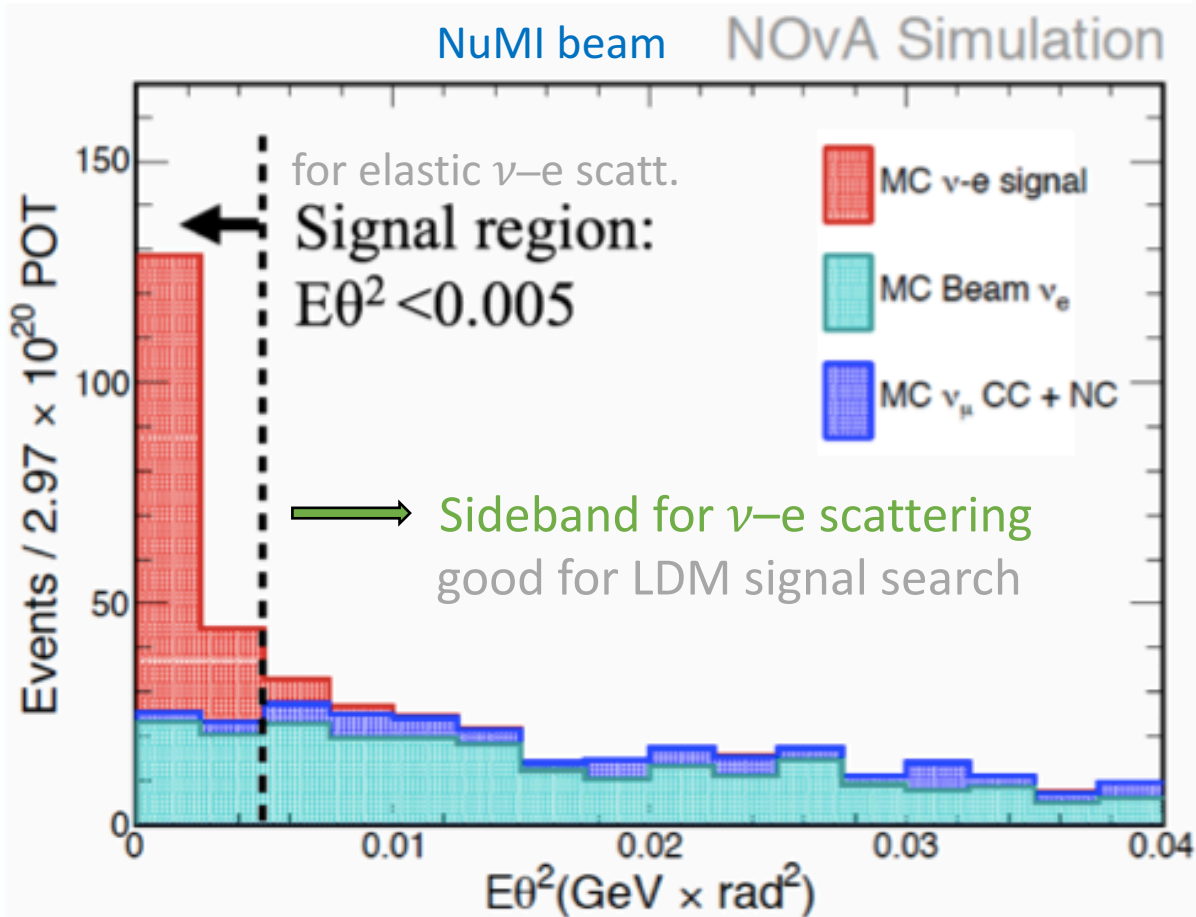
Theoretical paper MC simulation

- M_χ region: 6 MeV – 70 MeV
- M_{DP} region: 18 MeV – 210 MeV
- DM-Mediator coupling: $\alpha_D = 0.5$
- Kinetic $\gamma^* - V_{DM}$ mixing: $\epsilon = 10^{-3}$



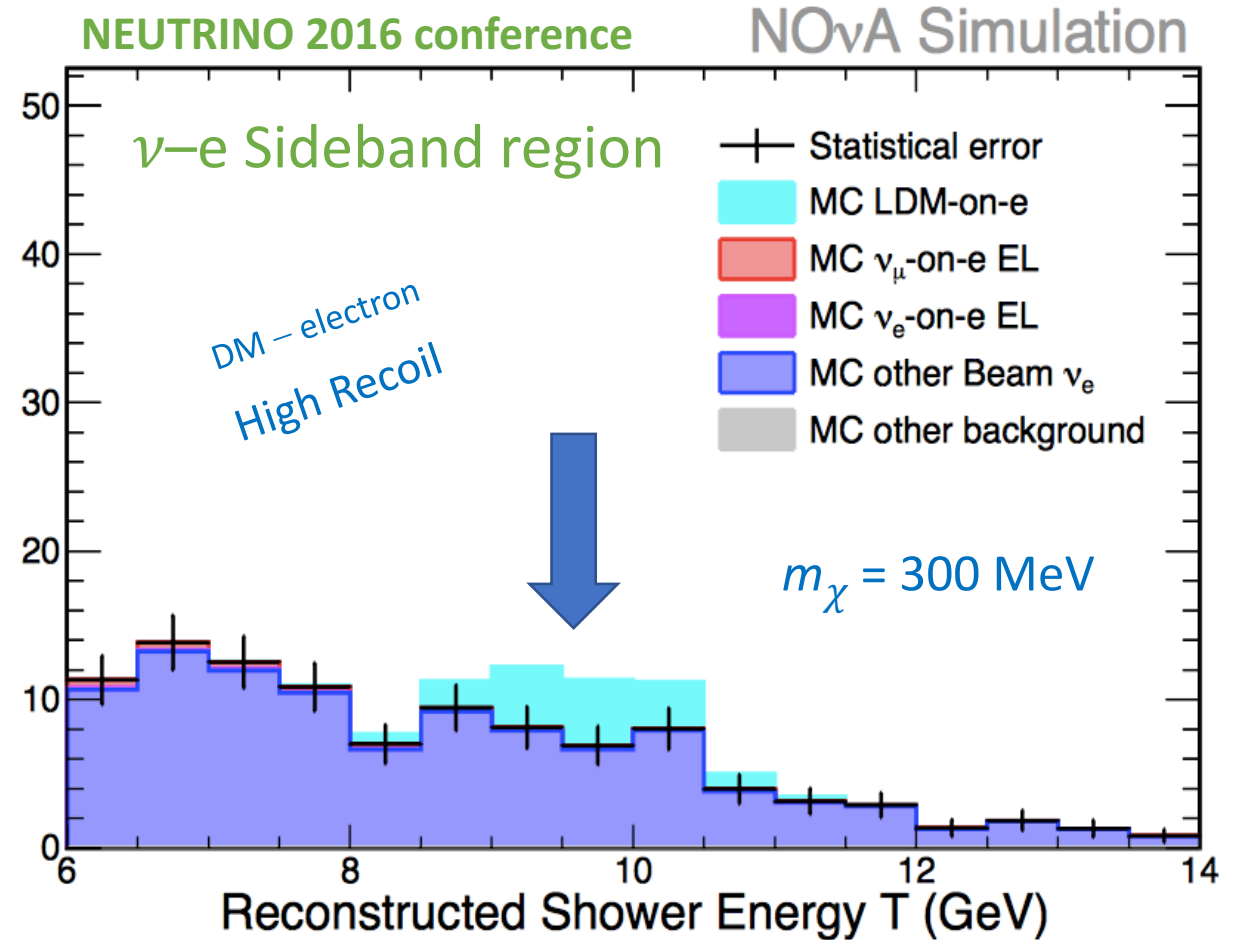
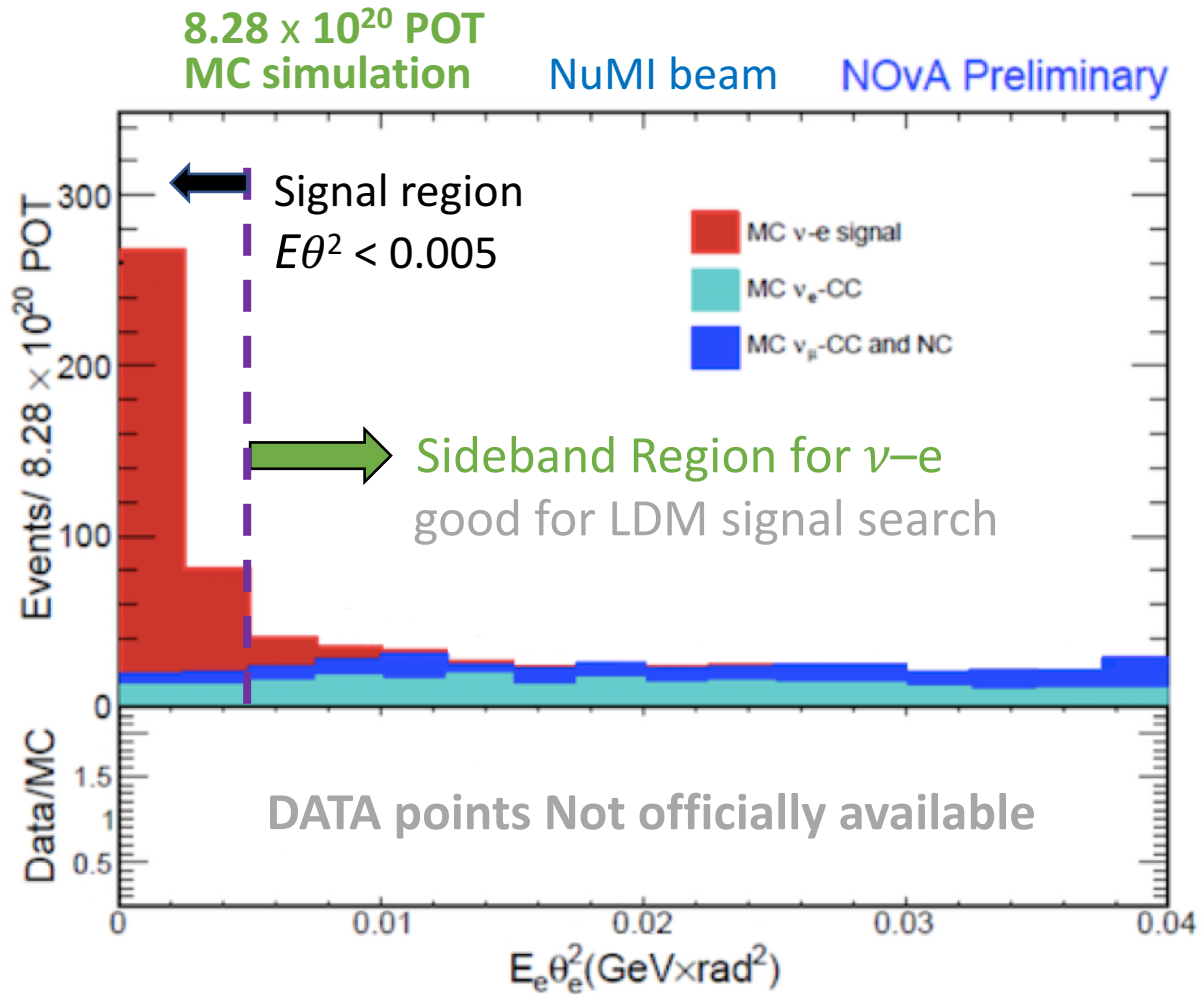
Excess of the elastic-like forward electron showers

➡ could mean: LDM signal in NOvA-ND

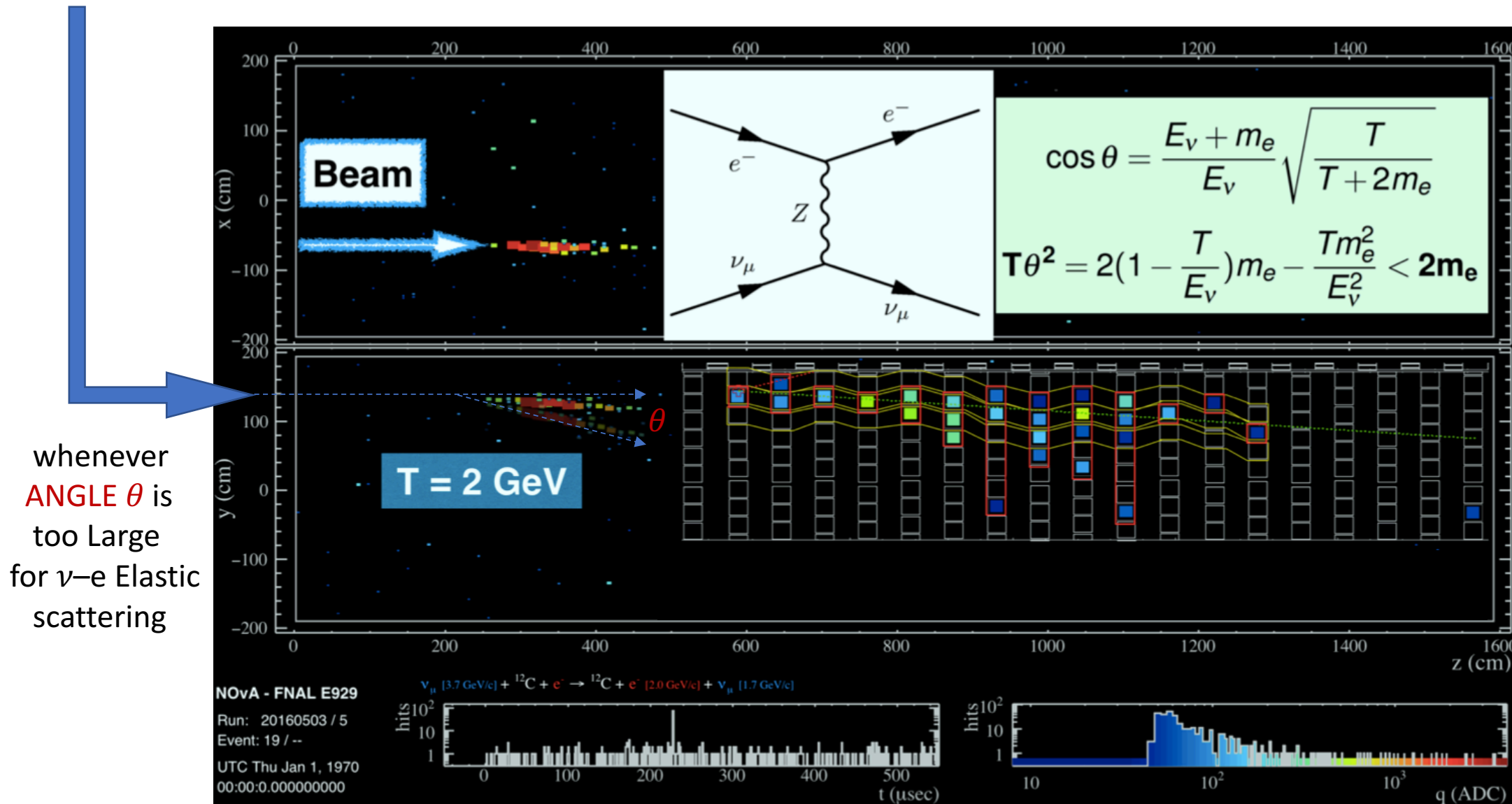


Excess of the elastic-like forward electron showers

→ could mean: LDM signal in NOvA-ND



Sideband Elastic electron showers may come from LDM

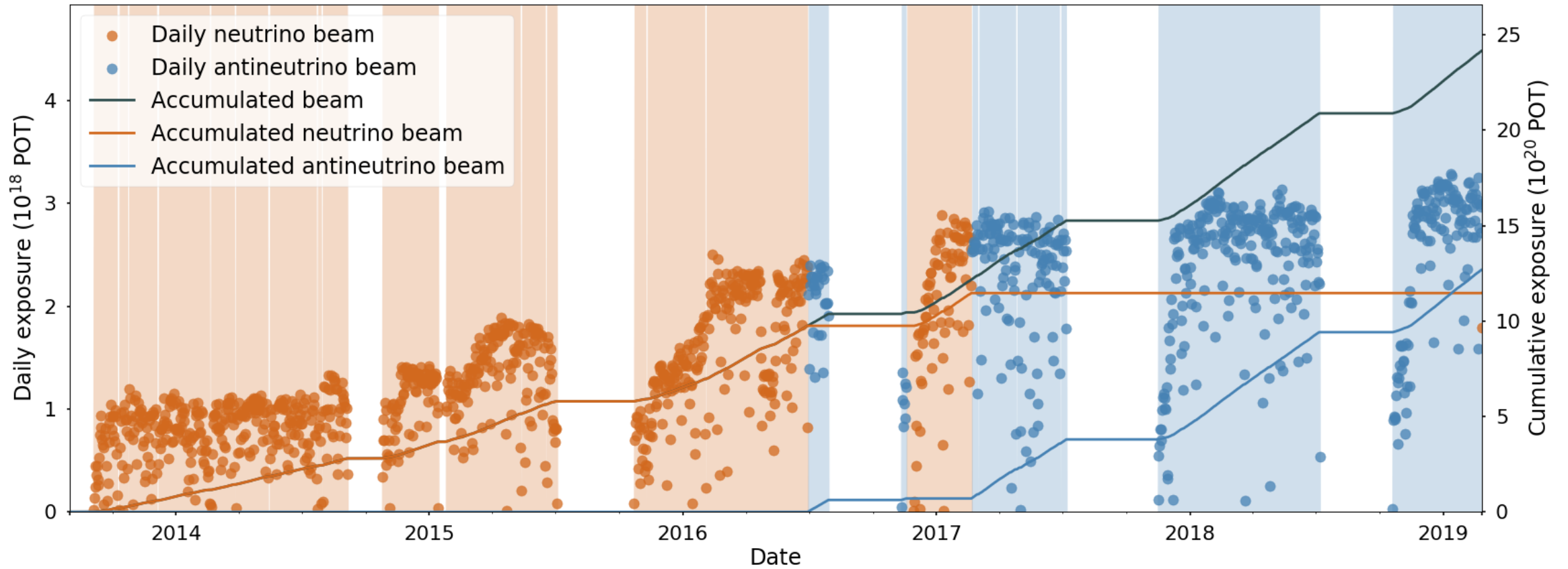


ANGLE θ in ν -e Elastic scattering is very small

whenever ANGLE θ is too Large for ν -e Elastic scattering

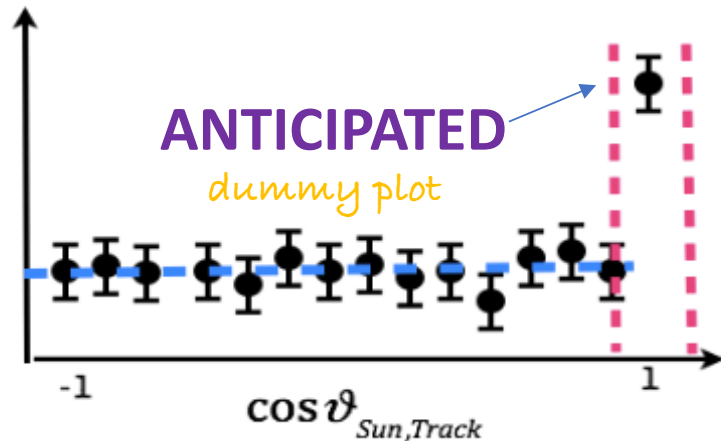
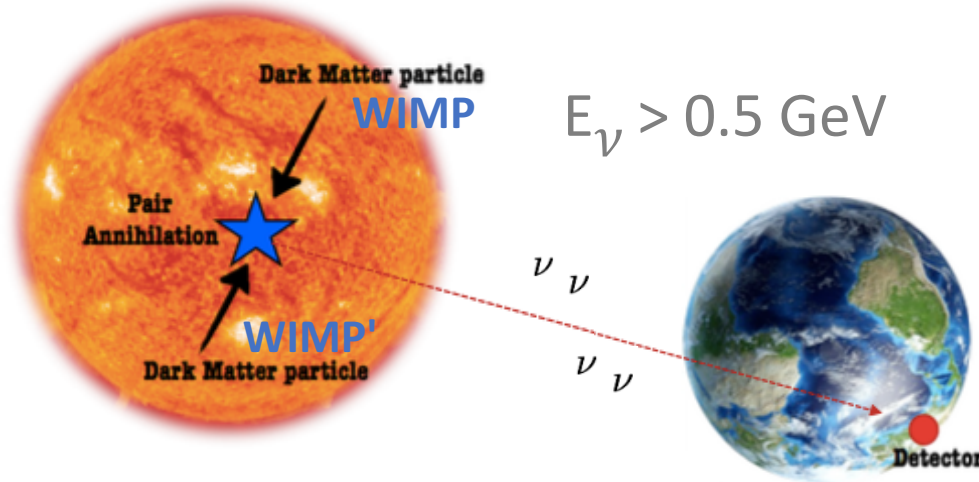
NOvA Statistics Accumulation: Σ POT \rightarrow 6×10^{21}

Gradually Increasing the NuMI beam intensity (power) \rightarrow 700 kW

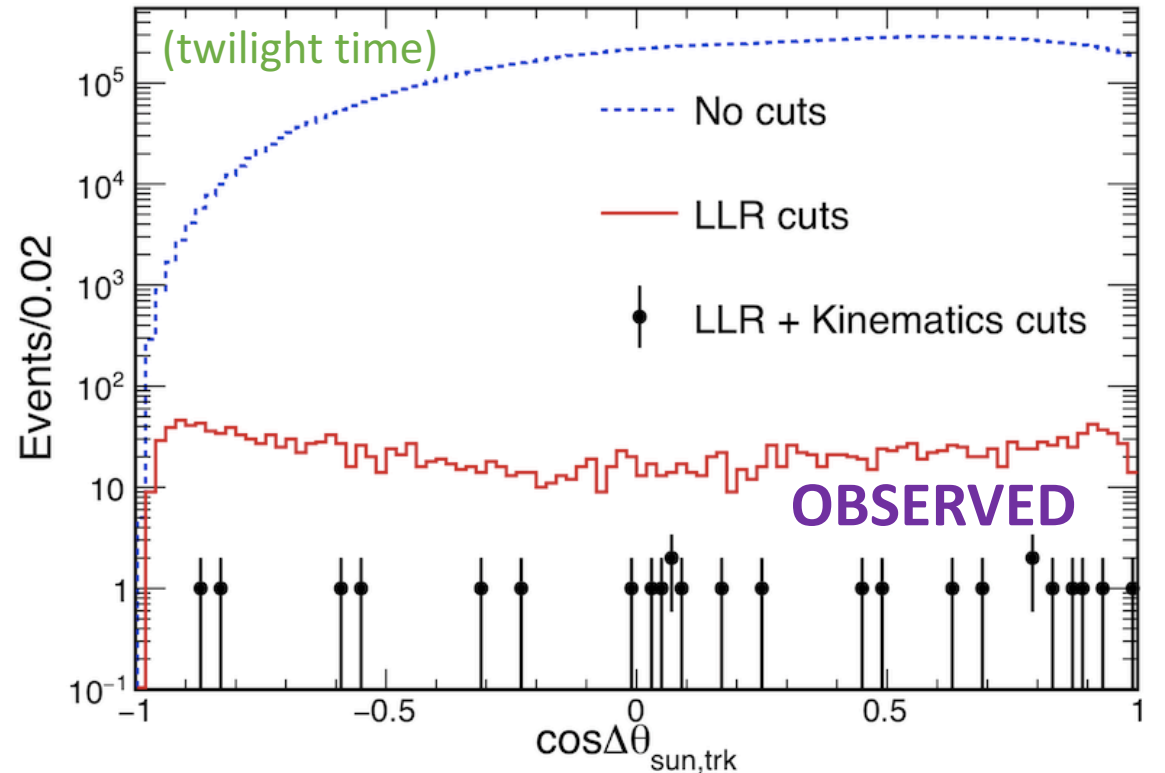


before Summary: 1) DM search in NOvA Far Detector Annihilation of DM in Sun \Rightarrow Upward going Muons

SUN: $L = 1 \text{ Au} = 1.5 \text{ M km}$
 $T_{\text{Sun}} = 10 \text{ Mega Kelvin}$

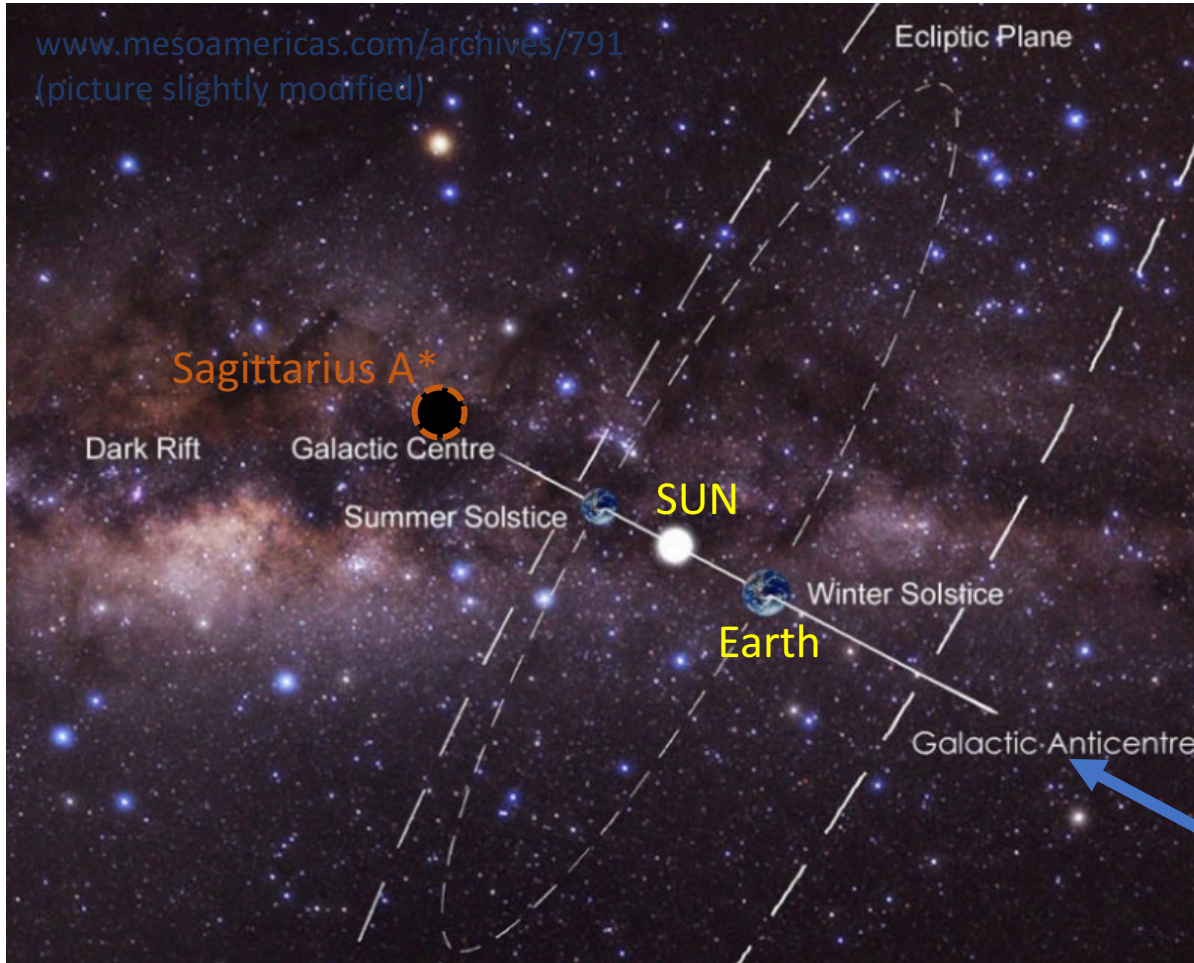


(Sun is at $\pm 10^\circ$ off the horizon)
SIDEBAND DATA REGION NOvA Preliminary



DATA taking + Analysis in Progress

before Summary: 2) **DM** search in Far+Near Detector
Interstellar or **DM Stream** \Rightarrow mini-SNova-like events
(low-energy neutrinos)




THIS EFFORT ASSUMES:

- * 'slow' **DM stream** in Milky Way
 - * **oriented FROM/TO** Galactic Center
 - * **DM Gravitational Focusing** by Sun
- Sun – Earth – Sagit. A* alignment
- * during Summer/Winter solstices

DATA taking in Progress

Possible interstellar
or DM stream

SUMMARY

- NOvA-ND can put competitive Limits on LDM^{production}
 for ^{120GeV} $p+C^{12} \rightarrow (M_{DP}: 20 - 200 \text{ MeV}) \rightarrow \chi\chi^\dagger$
Dark Mediator Mass Range
- DATA taking plan: until 2025 (POT $\rightarrow 6 \times 10^{21}$)
 improving several aspects (CNN & Syst. err.) not shown here
- + Far Det. NOvA Dark Matter Project Active
 search for WIMP annihilation in Sun + DM stream focusing

Picture taken 9.Nov. 2019, by: Roman Ponča / Czech /

Thank You and NDM-2020 organizers

for the Attention and Hospitality.

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