MiniBooNE Dark Matter Search

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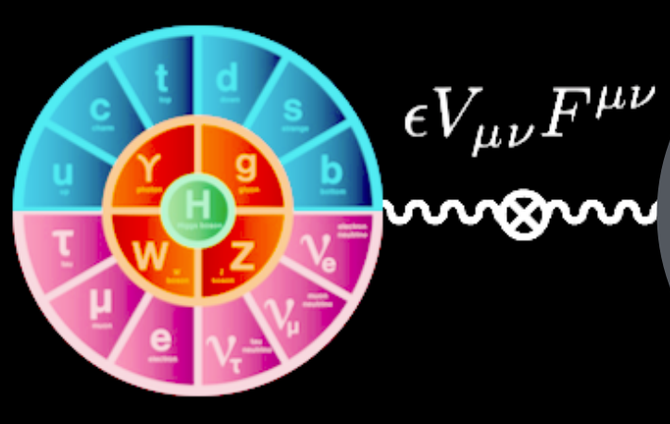
Argonne National Laboratory
for the MiniBooNE-DM Collaboration

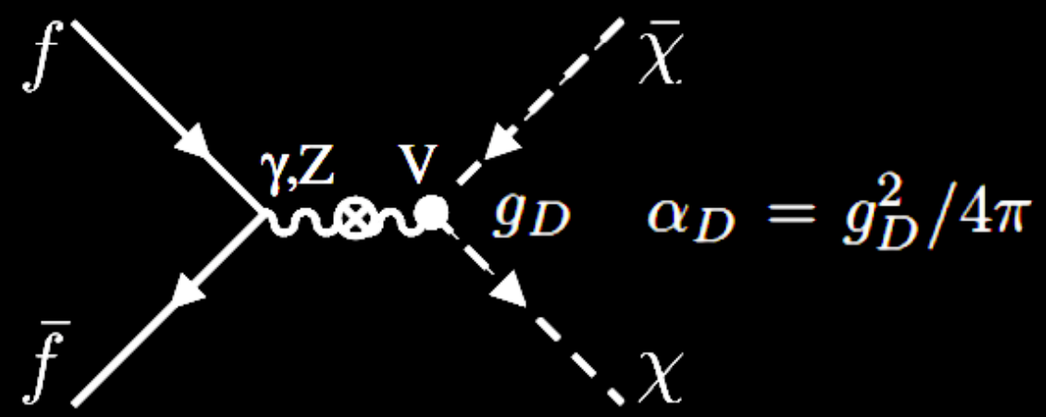
TeVPA 2017 Columbus OH

Dark Matter particles could belong to a Hidden Sector with coupling to the Standard Model



$\epsilon V_{\mu\nu} F^{\mu\nu}$

Dark sector



$$\mathcal{L}_{V,\chi} = |D_\mu \chi|^2 - m_\chi^2 |\chi|^2 - \frac{1}{4} V_{\mu\nu}^2 + \frac{1}{2} m_V^2 V_\mu^2 + \epsilon V_{\mu\nu} F^{\mu\nu} + \ldots$$

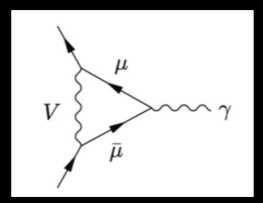
$$D_\mu = \partial_\mu - i g_D V_\mu \,, \quad g_D = \sqrt{4\pi\alpha_D}$$

4 parameters: m_χ, m_V, ϵ, α_D

B. Batell,M. Pospelov,A. Ritz, Phys.Rev. D 80, 095024 (2009)
P. deNiveville,D. McKeen,A. Ritz, Phys.Rev. D 86, 035022 (2012)

New gauge boson increases DM annihilation cross section to give correct relic density

- New vector mediator could be solution to g-2 anomaly



P. Fayet, Phys. Rev. D 75 115017 (2007)
M. Pospelov, Phys. Rev. D 80 095002 (2009)

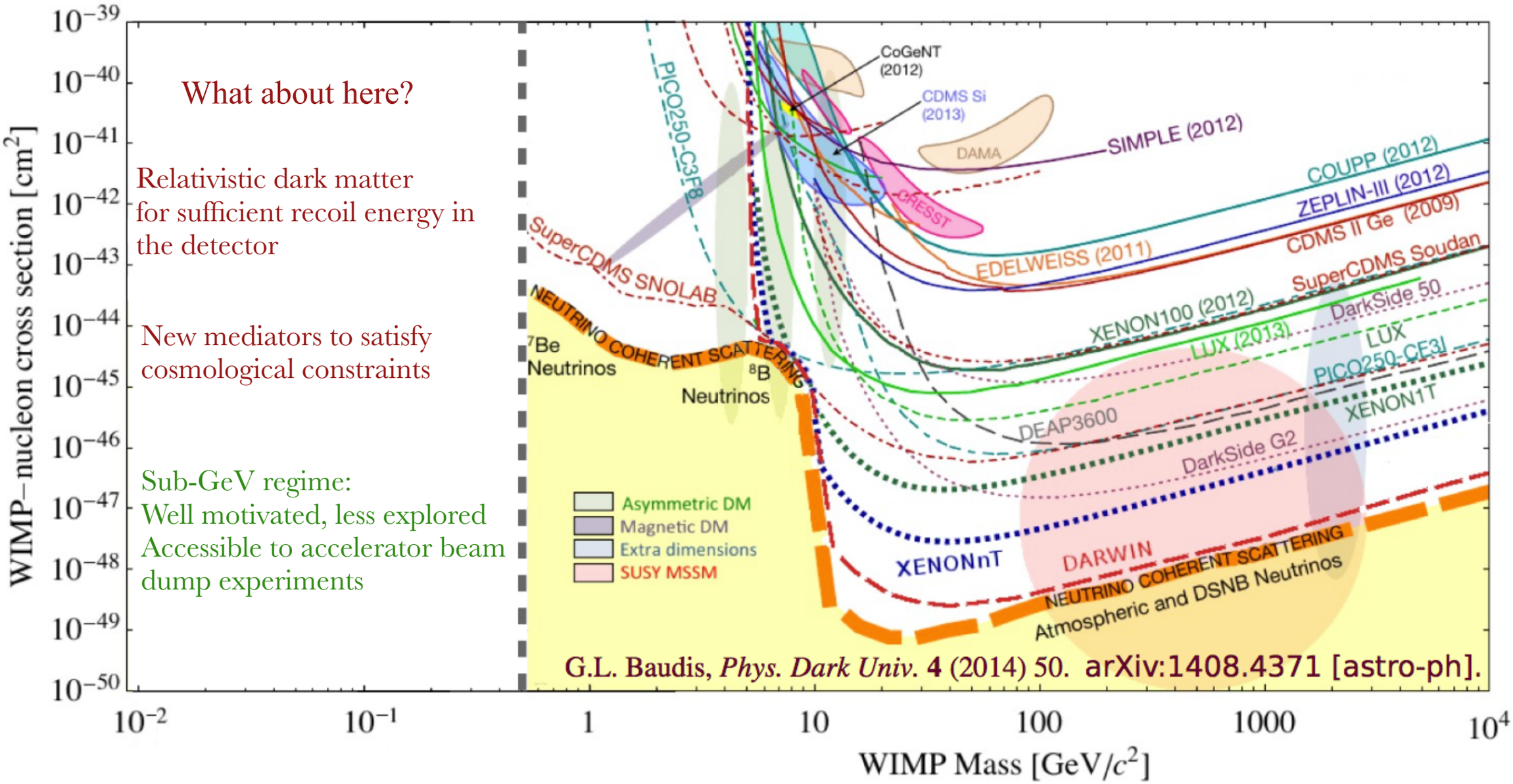
Explore an interesting region of phase space

What about here?

Relativistic dark matter for sufficient recoil energy in the detector

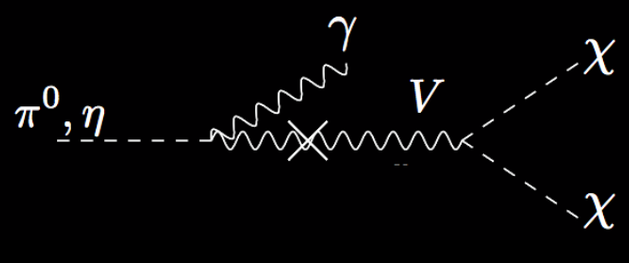
New mediators to satisfy cosmological constraints

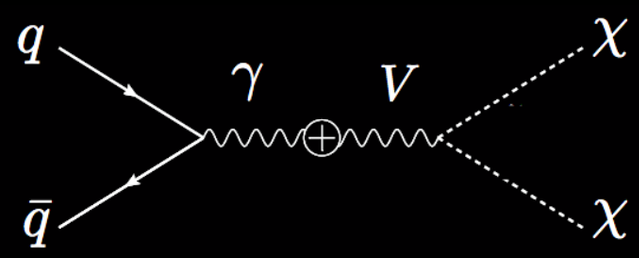
Sub-GeV regime:
Well motivated, less explored
Accessible to accelerator beam dump experiments

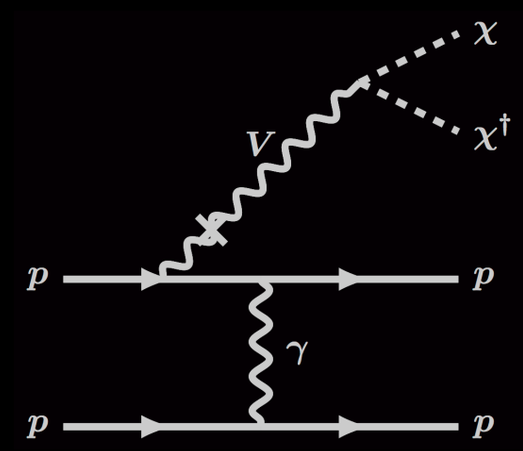


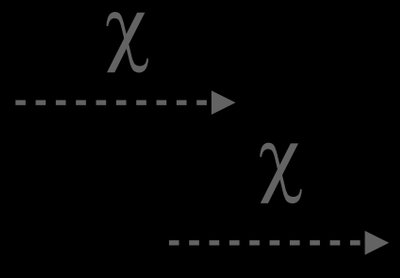
An intense beam, a large and sensitive detector, and a mechanism to suppress the Standard Model backgrounds

Production



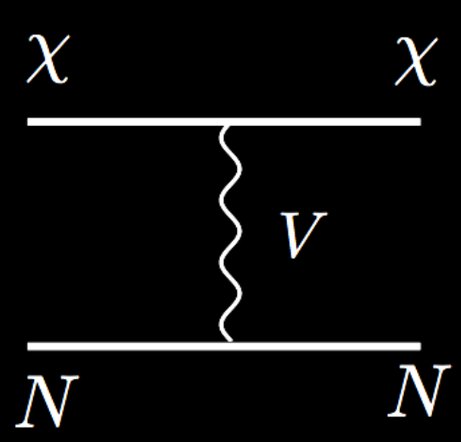


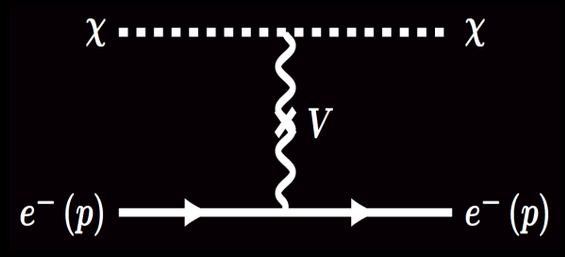


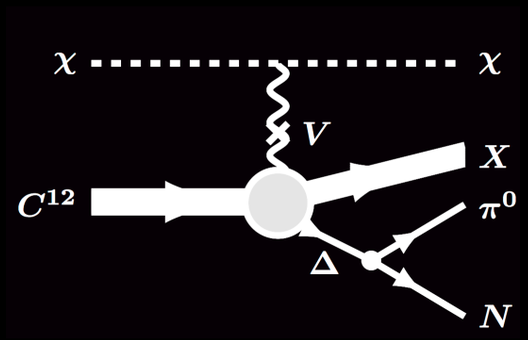


Boosted dark matter

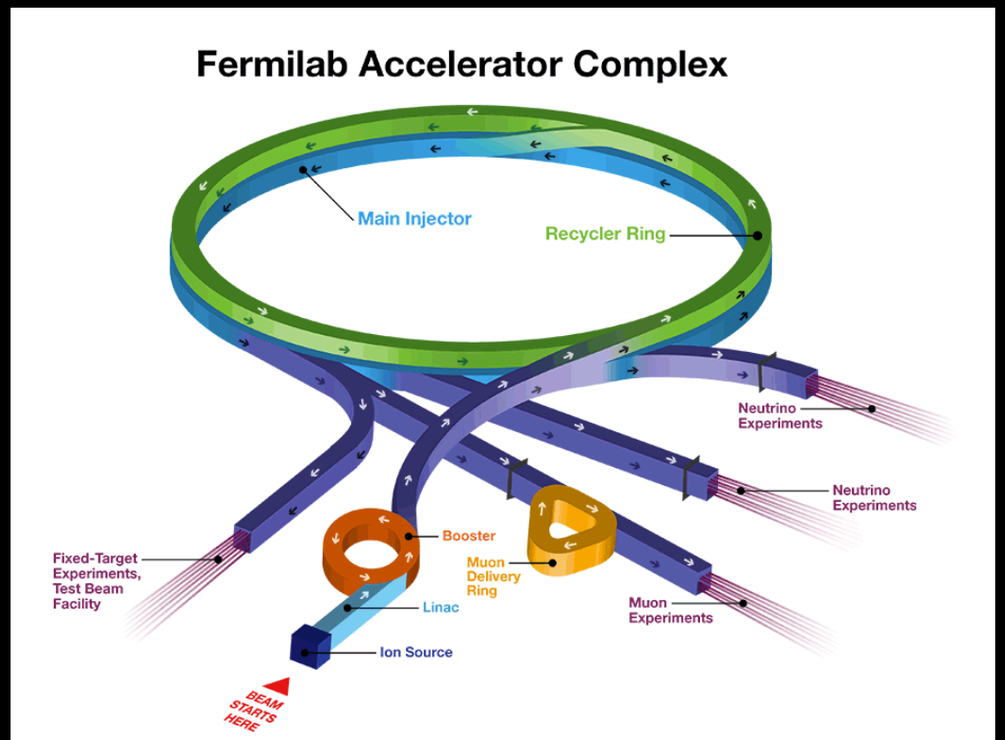
Detection







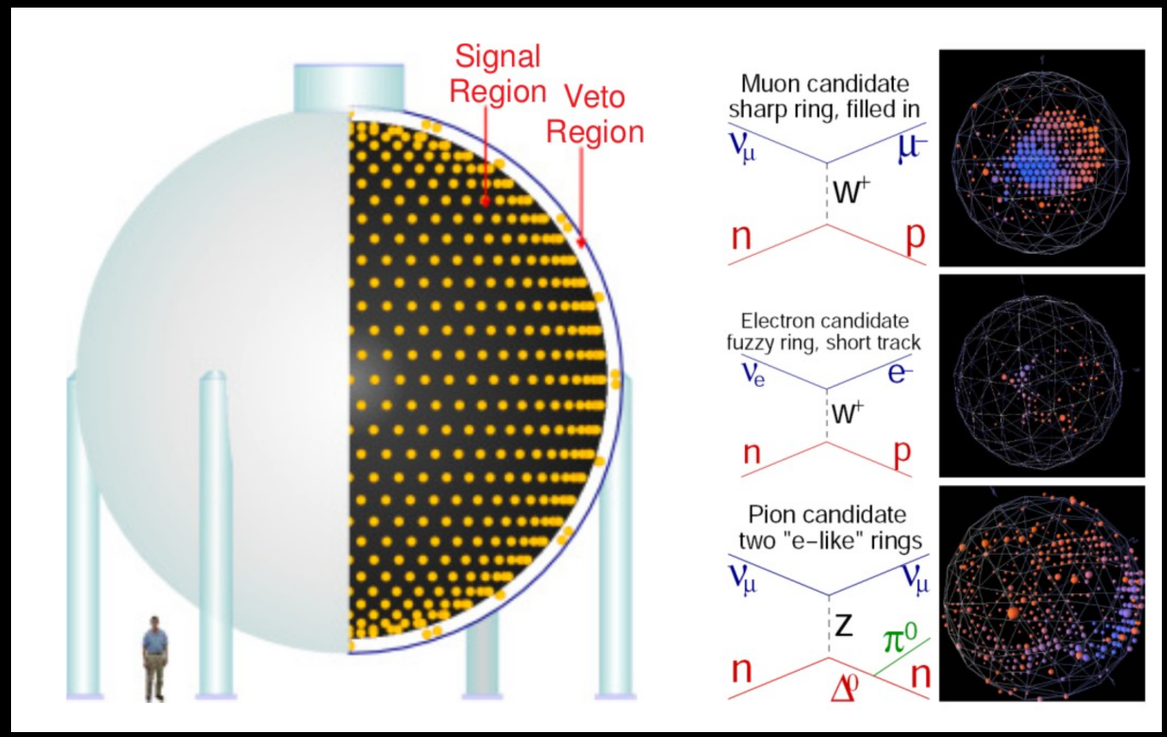
Booster Neutrino Beam



- 8 GeV protons from FNAL Booster
- Be target for neutrino production 540 m from the detector
- 50 ‘decay pipe’ with steel dump at the end

Phys. Rev. D81, 092005 (2010)

MiniBooNE Detector

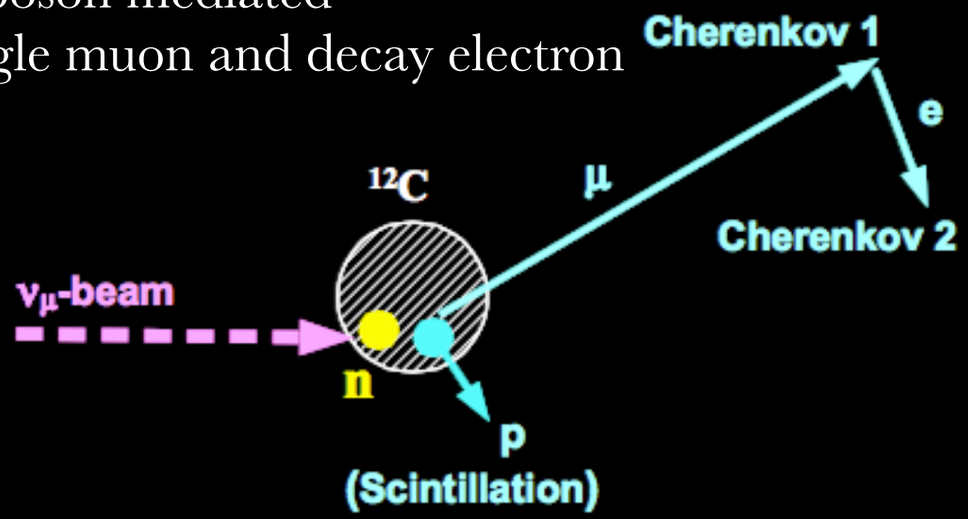


- 800 ton mineral oil Cherenkov detector
- Scintillation light from trace fluors
- Well understood experiment:
  - 11 oscillation papaers
  - 14 cross section papers
  - 1 detector NIM and Supernova paper
  - 18 PhD theses

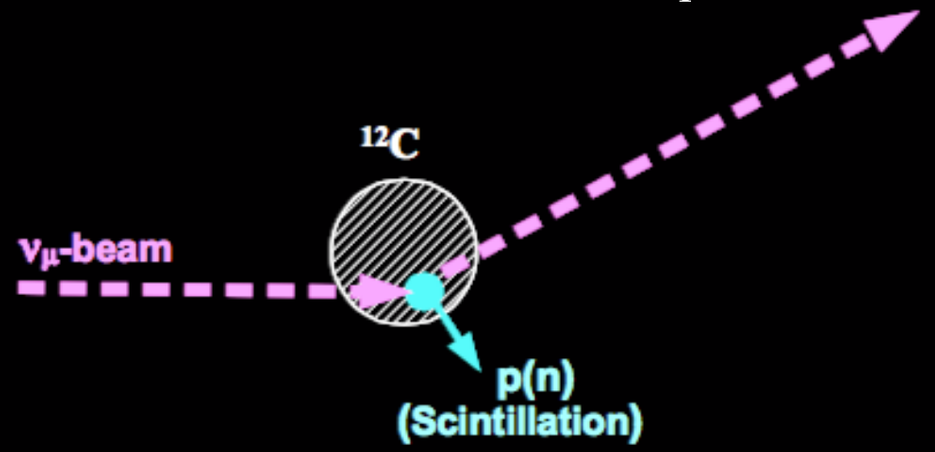
Well understood beam and detector

CCQE and NCE interactions

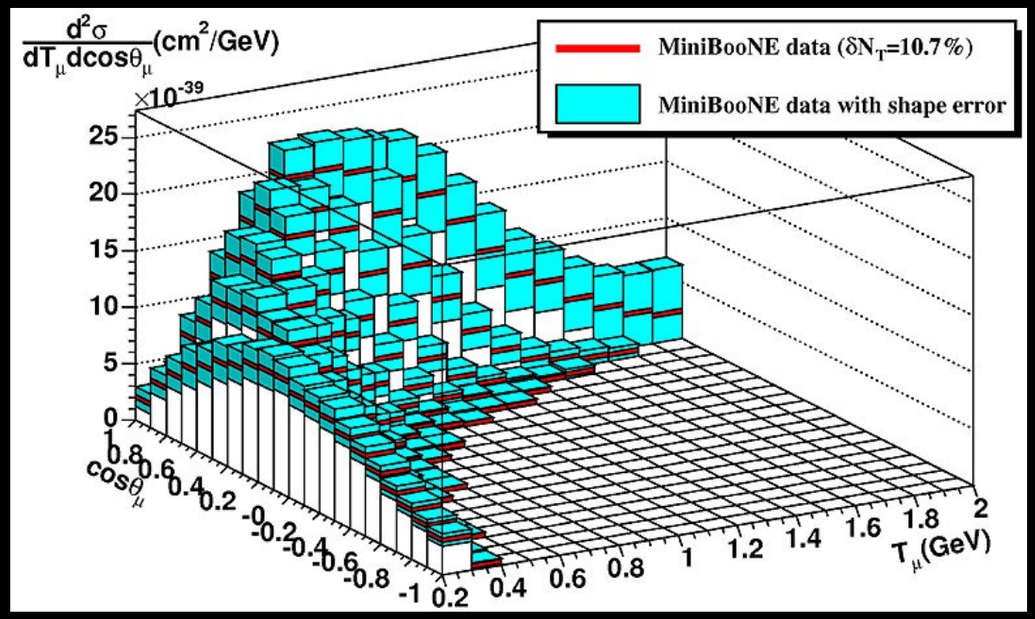
- Charged Current Quasi-Elastic
- W boson mediated
- Single muon and decay electron



- Neutral Current Elastic
- Z boson mediated
- Scintillation with no muon or pion

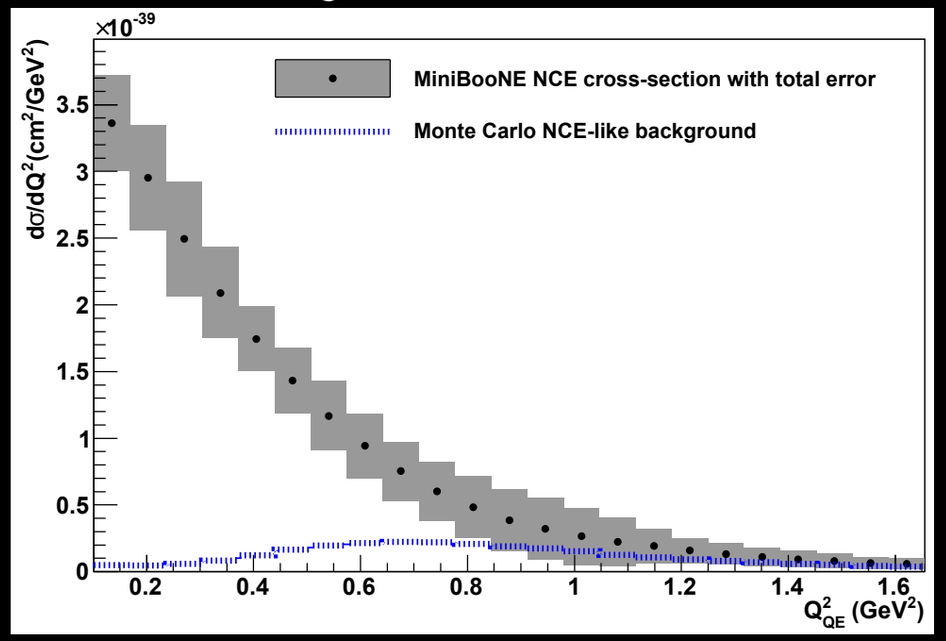


Double differential cross section measurement



Phys. Rev. D81, 092005 (2010)

NCE cross section measurement and ratio to CCQE



Phys. Rev. D82, 092005 (2010)

CCQE and NCE interactions

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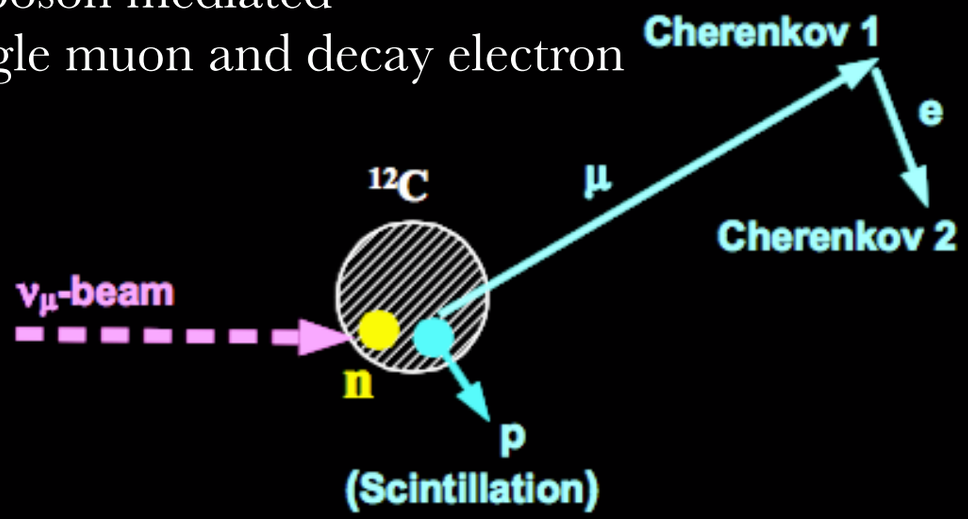
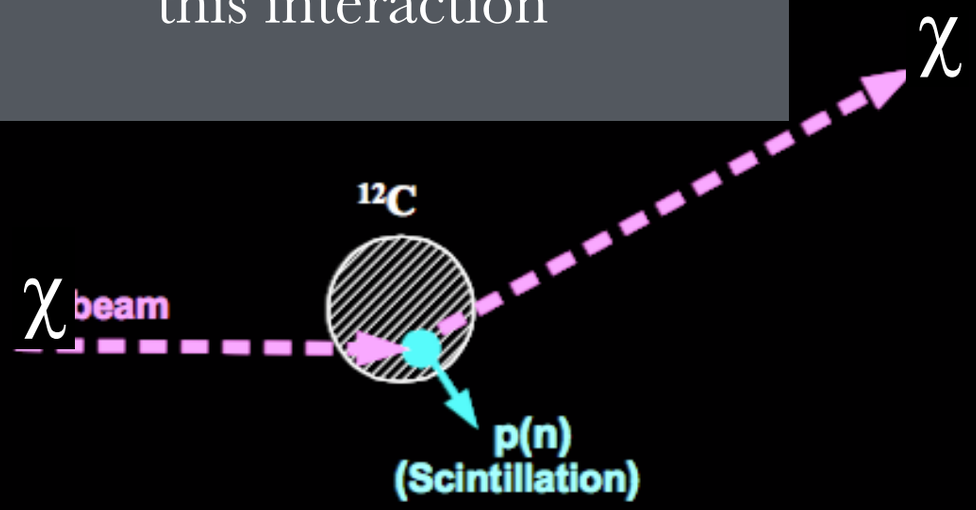
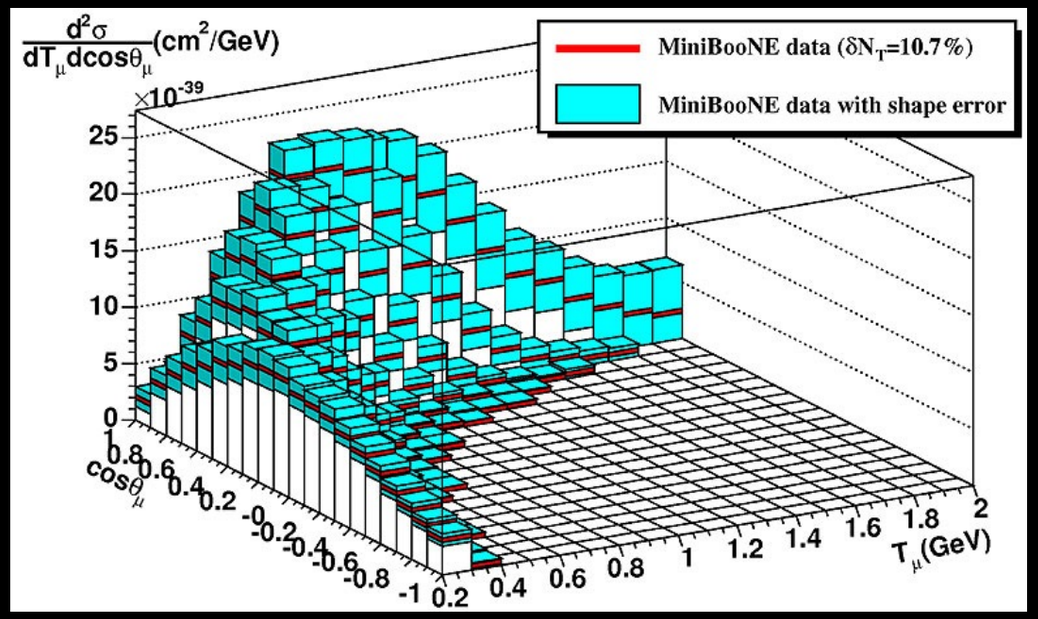


Dark matter will mimic this interaction



Double differential cross section measurement



Phys. Rev. D81, 092005 (2010)

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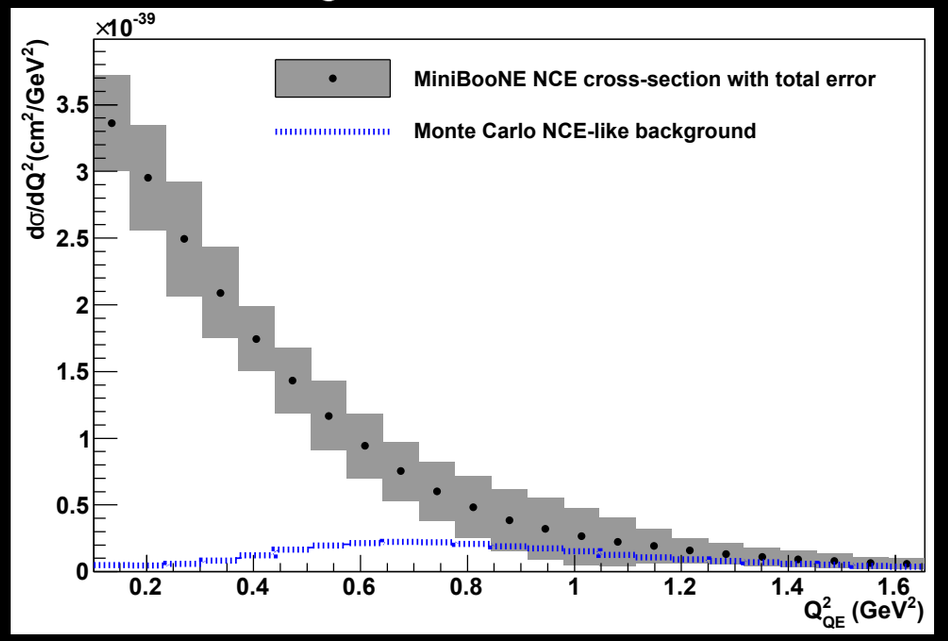
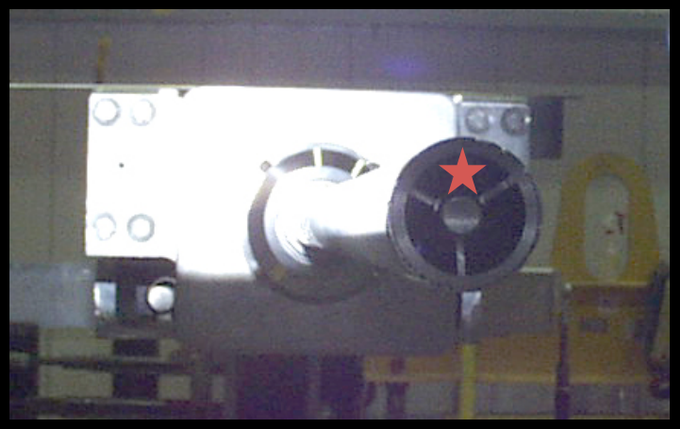
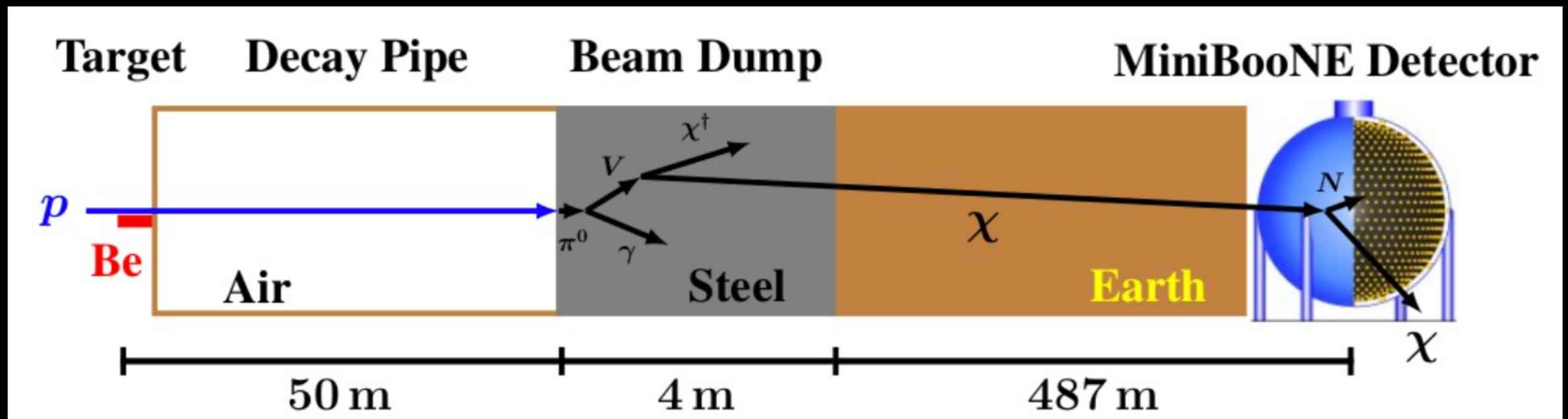


Phys. Rev. D82, 092005 (2010)

Beam dump mode: Reducing neutrino background

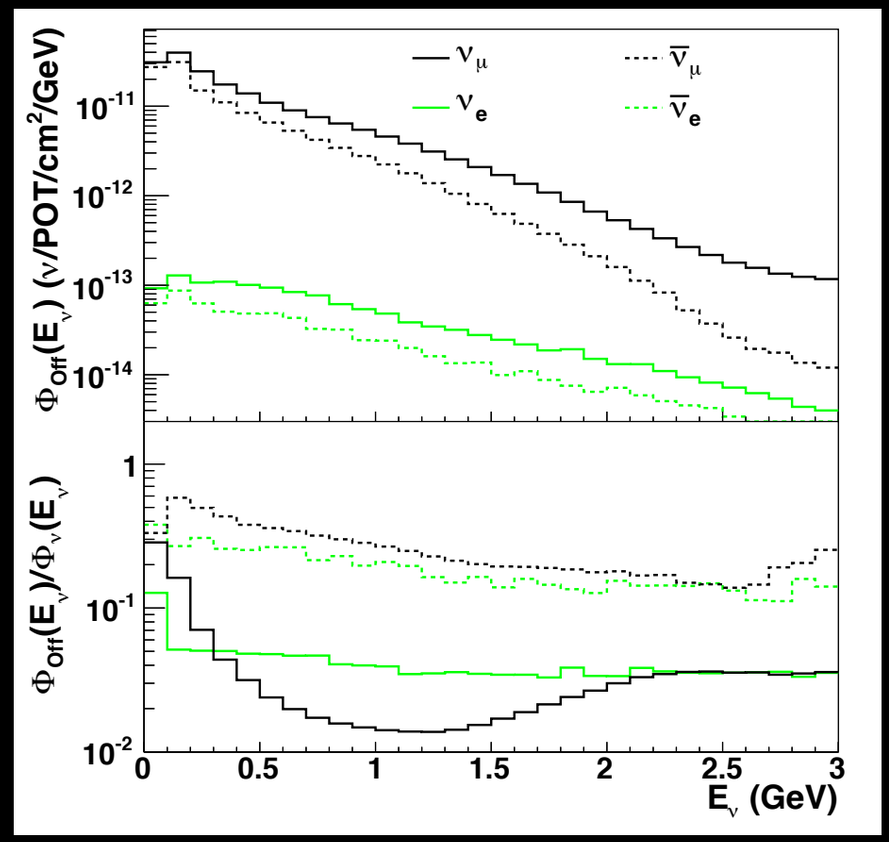


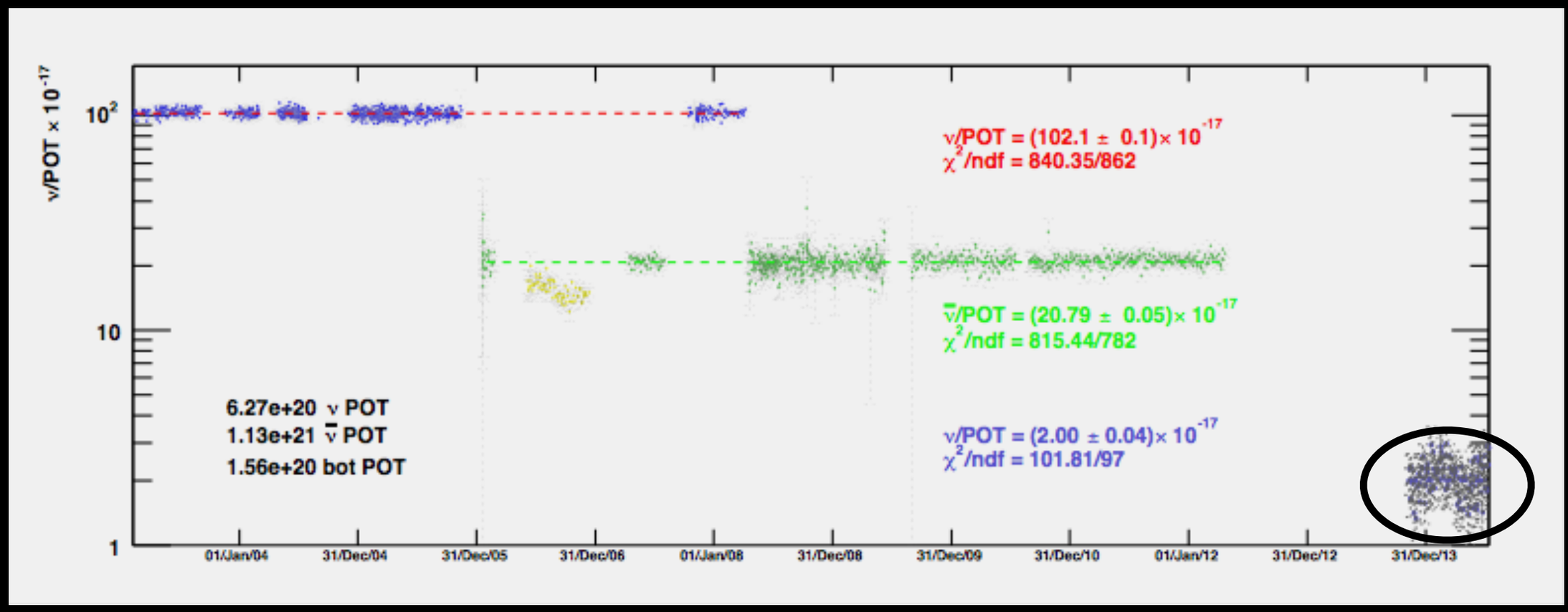
- Protons steered off-target towards 50 Fe dump
- Charged mesons absorbed before decay to neutrinos
- Neutral mesons unaffected



Beam dump mode: Reducing neutrino background

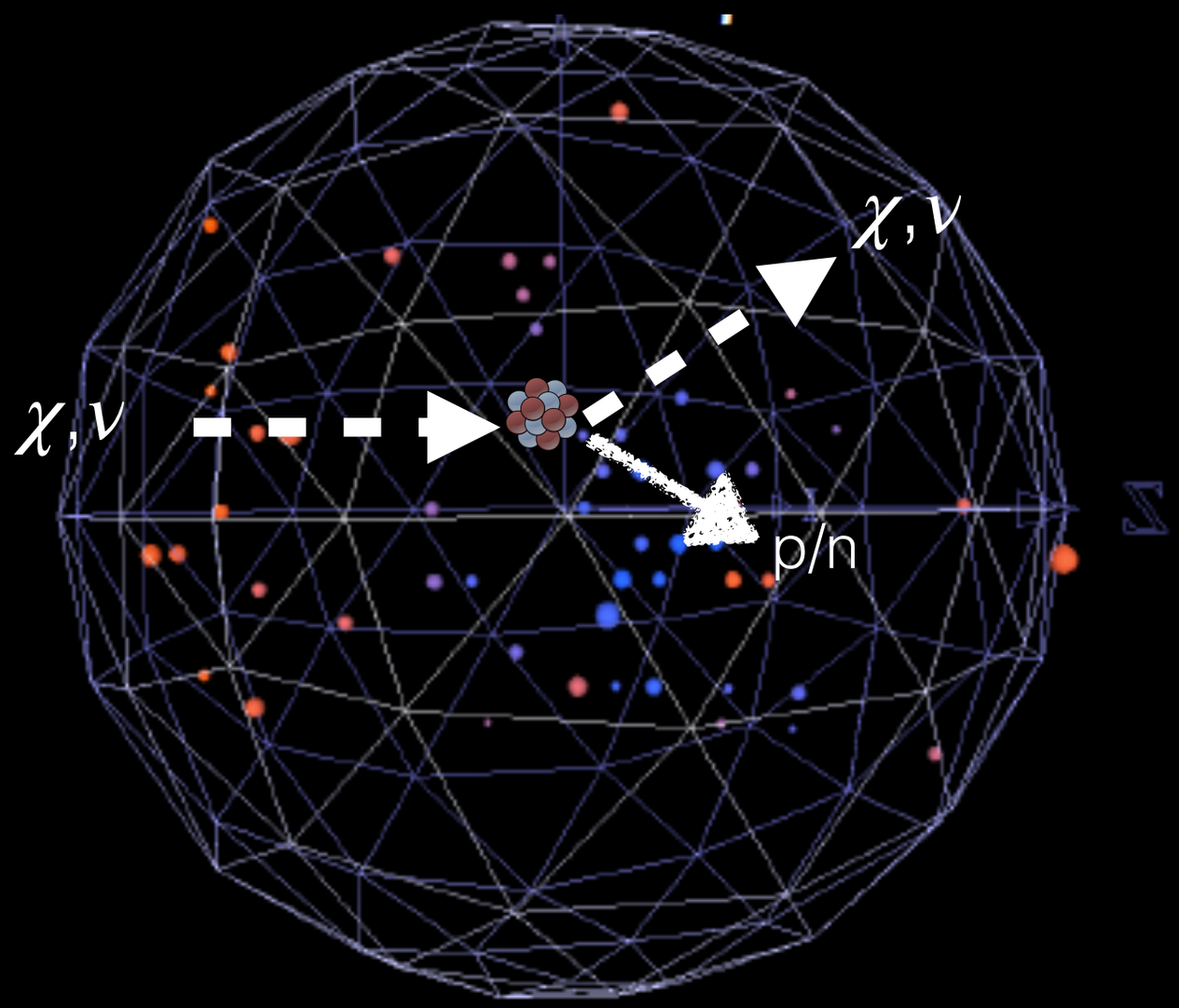
- Flux reduced by factor ~30
- Event rate reduced by factor of ~ 50
- Stable run for 9 months in this mode





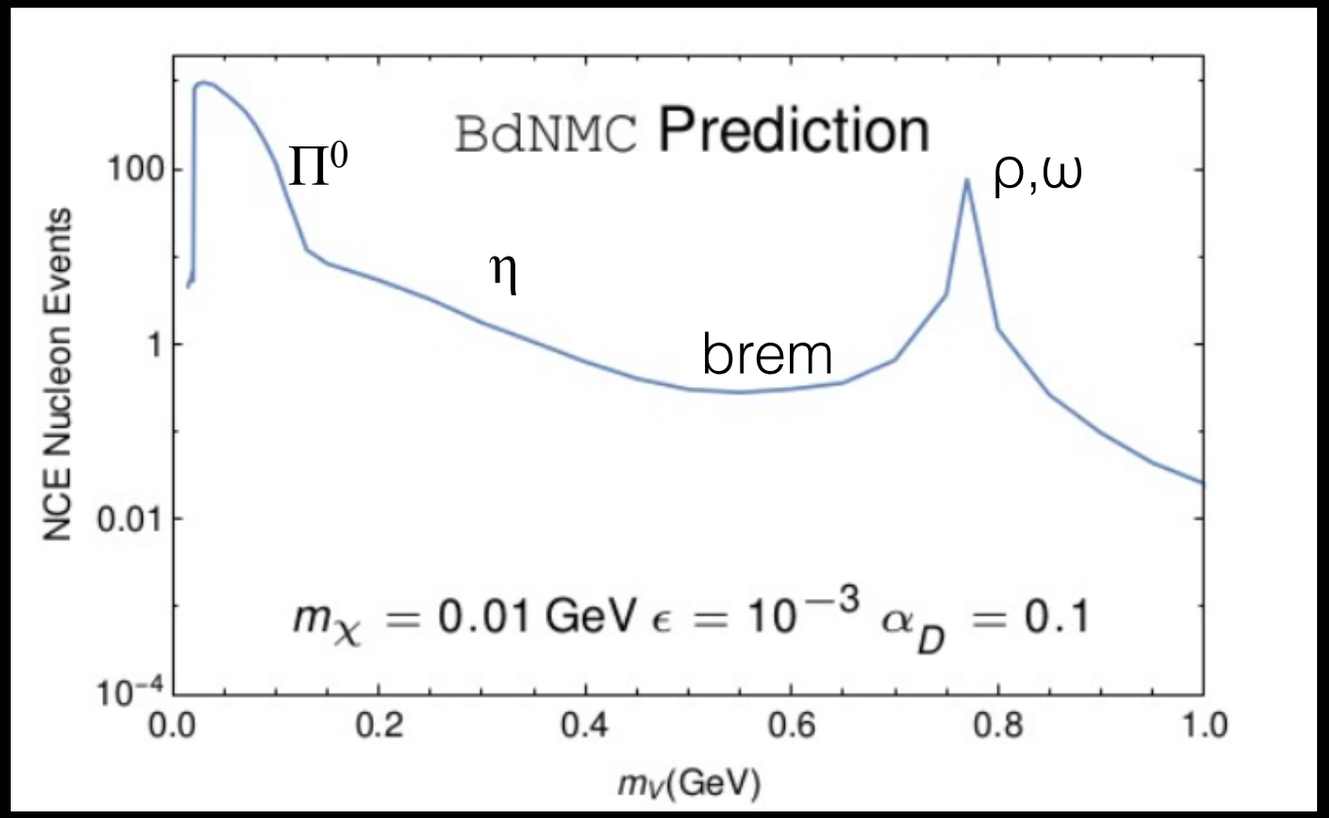
Event selection

- Protons detected by scintillation light
- Neutrons via secondary scatter off protons
- Selection cuts to isolate single track proton-like events and reject beam related and cosmic backgrounds
  - Event coincident with beam time
  - No veto activity



Dark Matter simulation

- BdNMC :Proton beam fixed target simulation tool
- Includes Π^0, η and Bremsstrahlung processes

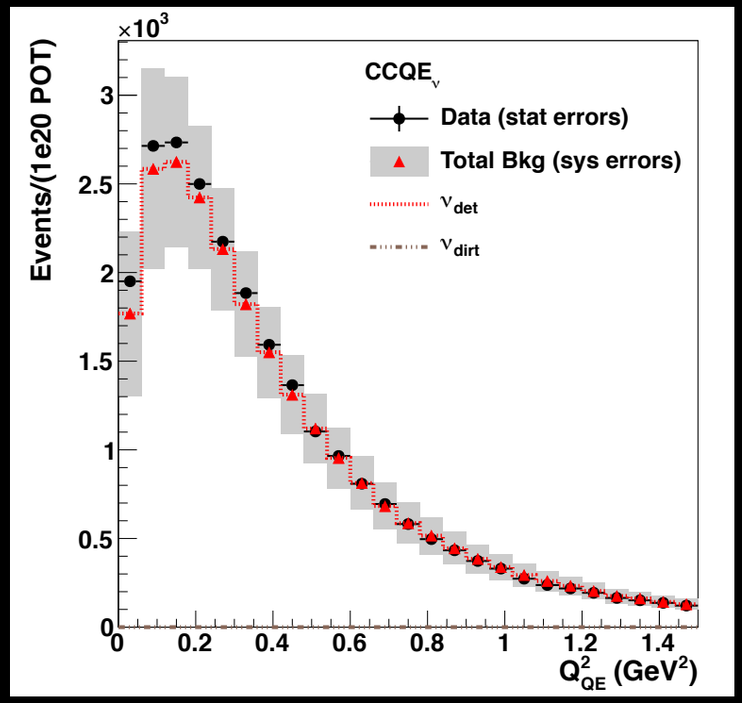


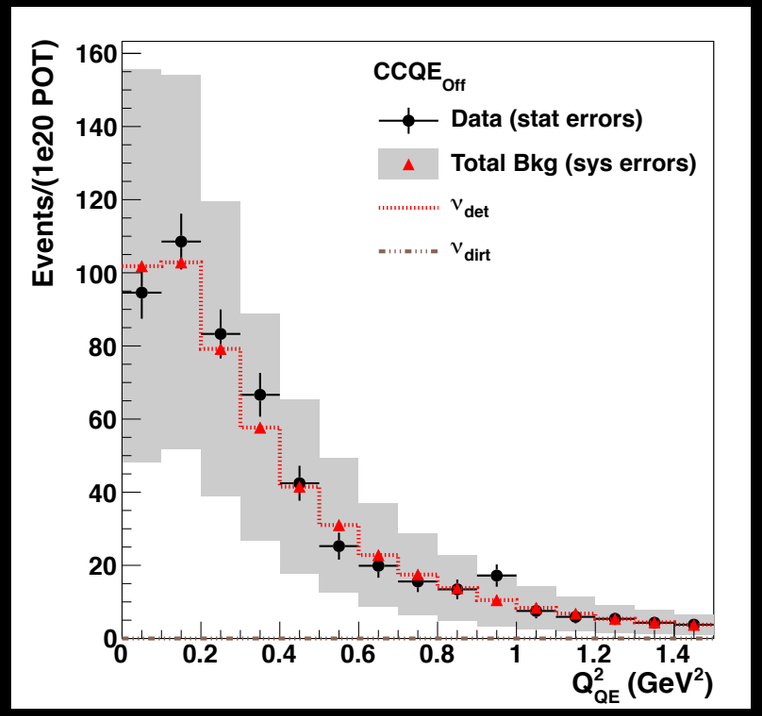
deNivervile, Chen, Pospelov, Ritz

https://github.com/pgdeniverville/BdNMC/releases

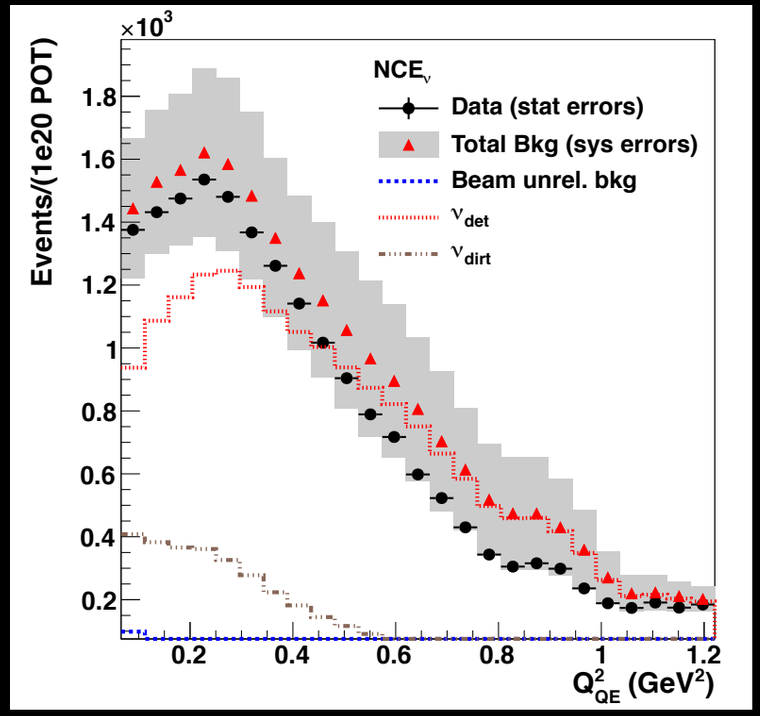
Analysis Strategy

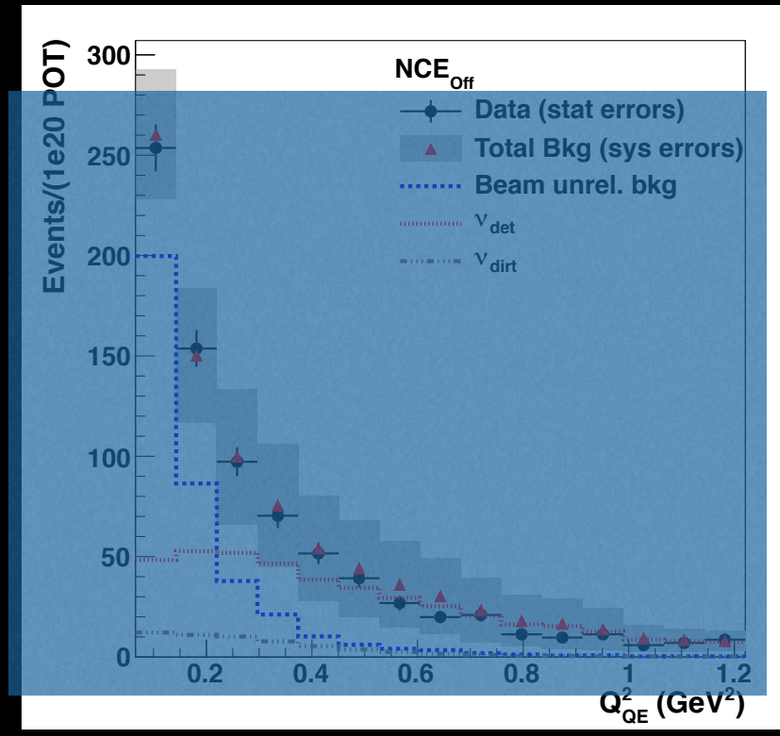
- Simultaneous fit to 4 disctrbutions
  - $CCQE_{\nu}$ neutrino mode
  - $CCQE_{off}$ beam-dump mode
  - NCE_{ν} neutrino mode
  - NCE_{off} beam-dump mode



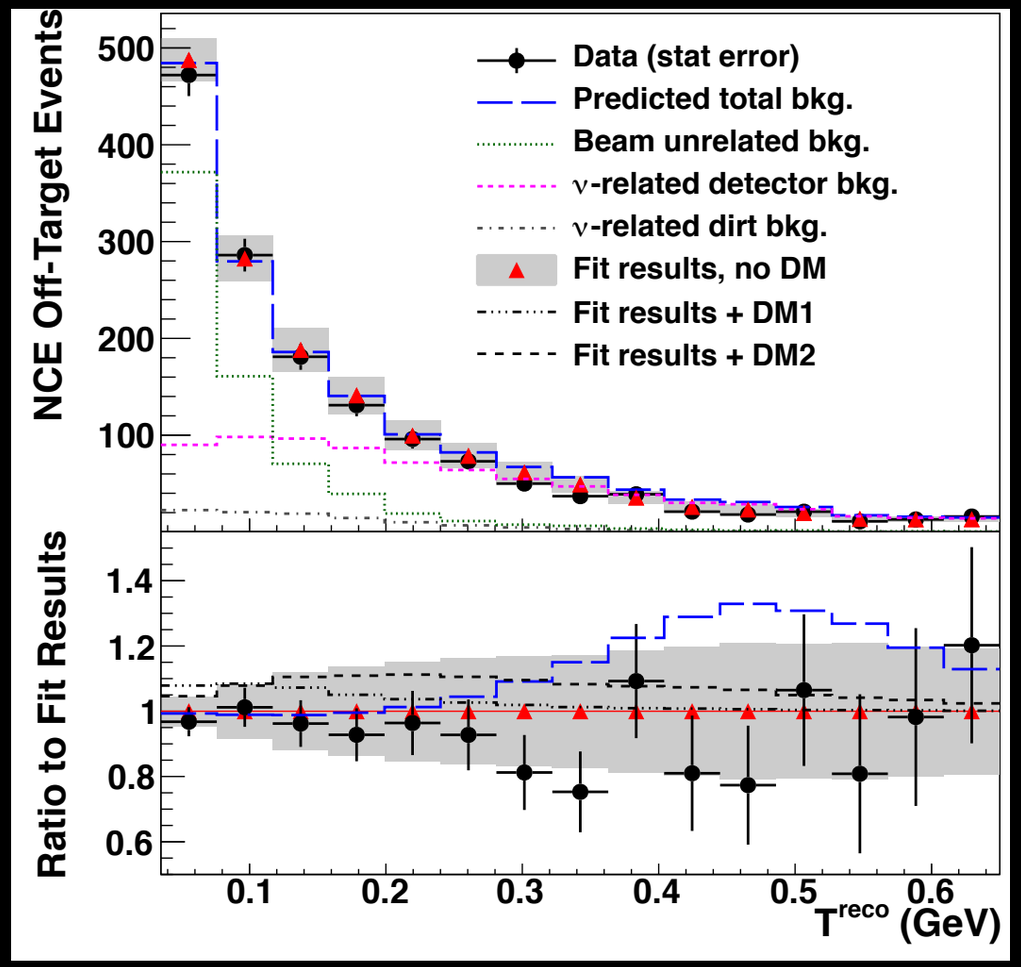


- CCQE ratios help reduce flux uncertainty while NCE ratio reduce cross section uncertainty



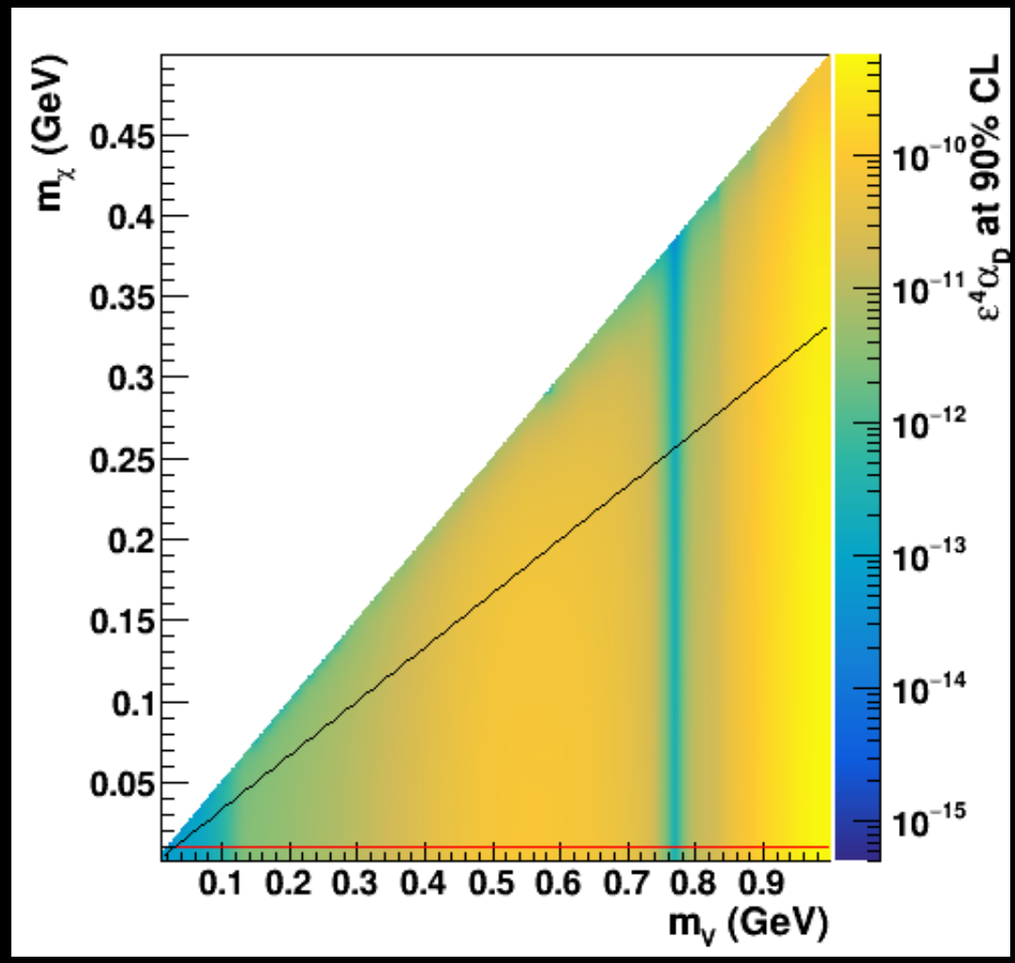


Results



	#events	uncertainty
Beam unrel. bkg	697	
Beam rel: ν_{det} bkg	775	
Beam rel: ν_{dirt} bkg	107	
Total Bkg	1579	34% (pred. sys.)
Data	1465	3% (stat.)
Fit Results	1548	13% (fit effective error)

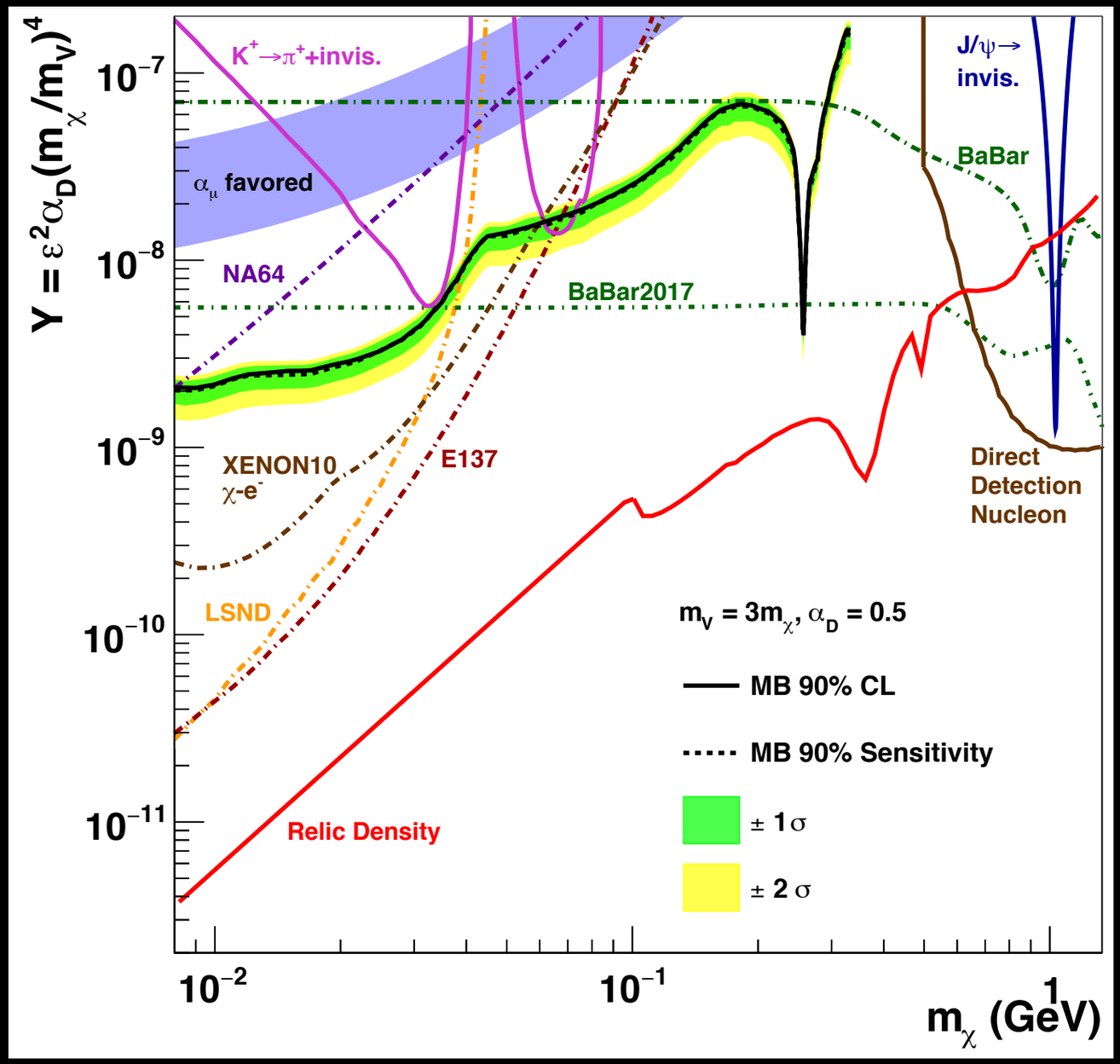
- Data consistent with background



90% Confidence Limits

- CL on value of $\varepsilon^4\alpha_D$ for given m_V and m_χ
- Slice to compare to other experiments
- Considered on-shell decays ($m_V > m_\chi$)

Results

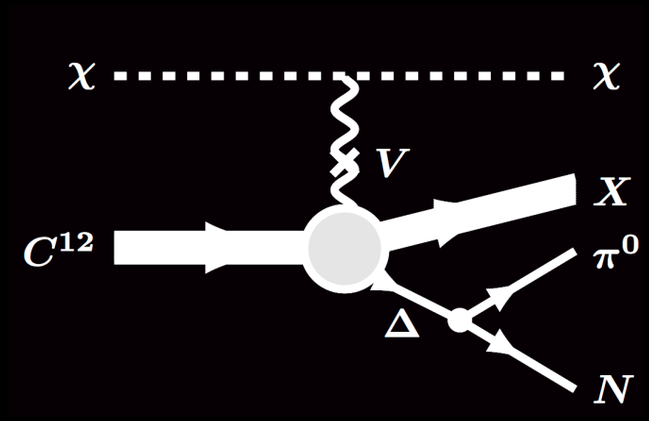


solid lines: DM coupling to quarks/nucleons
solid-dashed lines: DM coupling to electrons

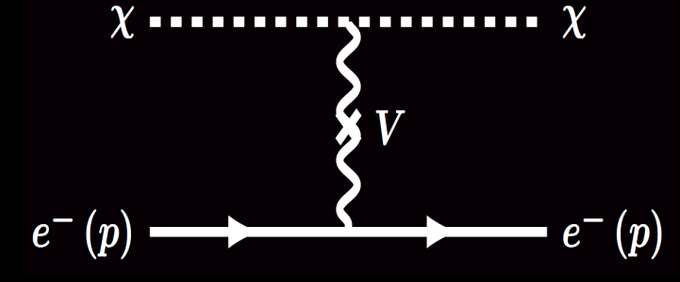
Phys. Rev. Lett. 118, 221803 (2017)

Future results from MiniBooNE-DM

Dark matter Δ resonance scattering with π^0
- Neutrino NC π^0 main background
- Clean signal, low beam unrelated background

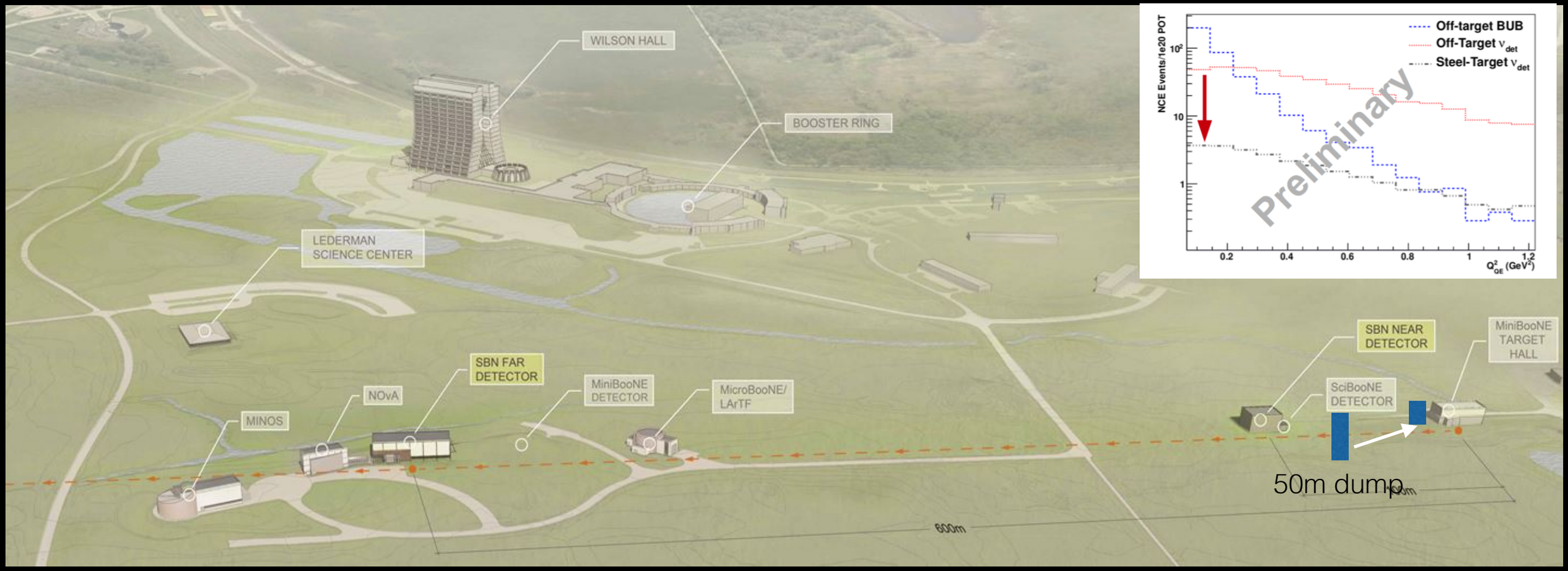


Dark elastic scattering off electrons
- Neutrino-electron main background
- Very forward peaked signal

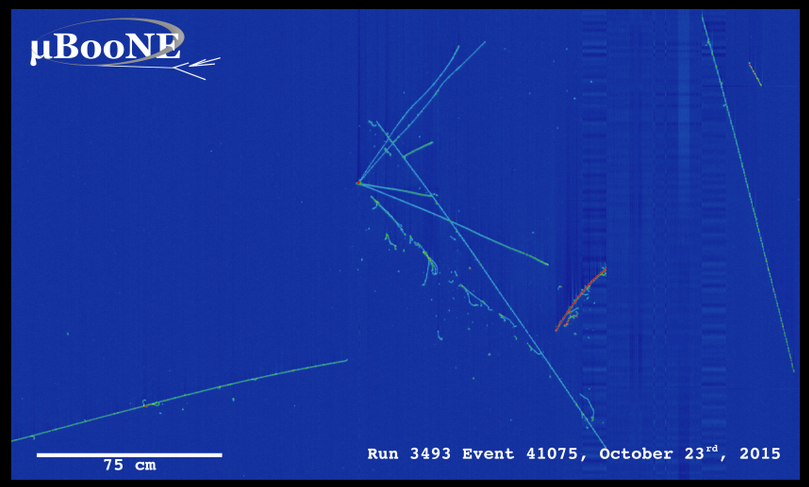


Using time-of-flight
- Dark matter delayed as compared to neutrinos

Future Prospects



- Number of high-resolution detectors in pipeline on BNB (SBN program)
- A dedicated beam-dump idea
- LOI submitted to Fermilab PAC



For details, see talk by R. Van de Water @ U.S. Cosmic Visions 2017

Summary:

- First dedicated proton beam dump search for dark matter by MiniBooNE-DM
- Published results for dark matter -nucleon scattering. Analysis on other dark matter scattering channels ongoing
- Exploring future opportunities at Fermilab SBN program