



Latin American Contributions to the MiniBooNE experiment

Alexis A. Aguilar-Arévalo (ICN-UNAM)
(for the MiniBooNE collaboration)

Neutrinos Latin America Workshop
Fermilab, April 27-28, 2016

Outline

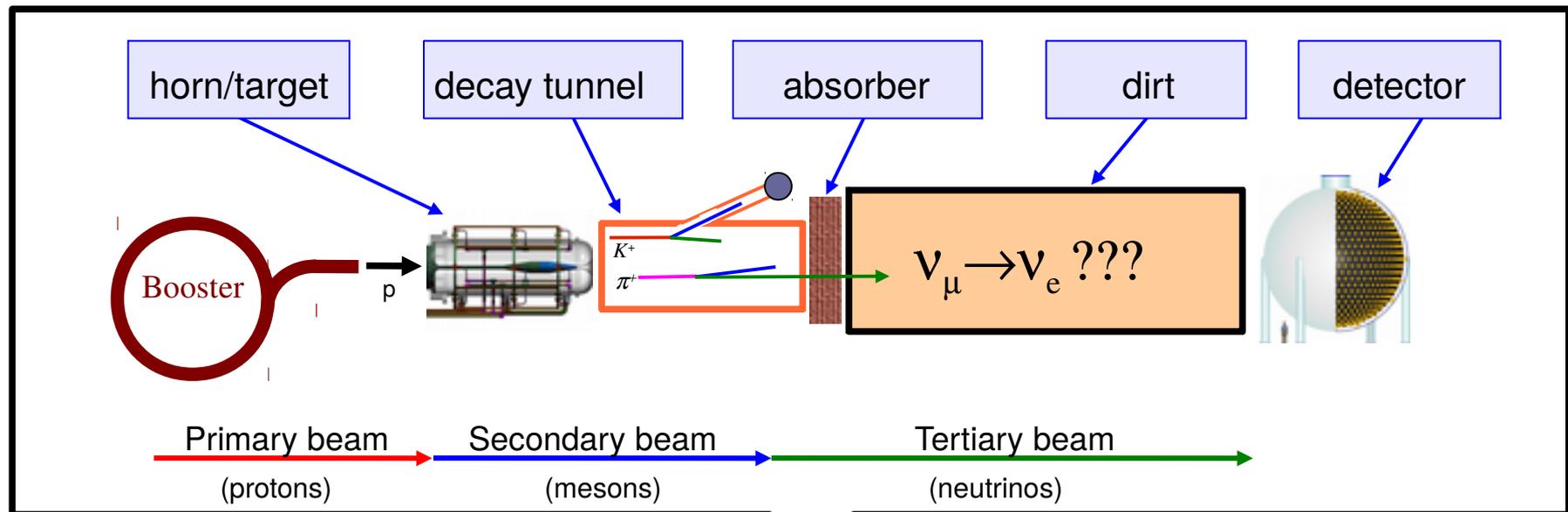
- MiniBooNE and MiniBooNE-DM
- Latin American collaborators in U.S. institutions
 - Brazil (@FNAL)
 - Mexico (@ Columbia University)
- Contributions from Mexico
- Summary

Mini-Booster Neutrino Experiment

Short Baseline neutrino oscillations experiment at the FNAL
Booster neutrino beam.

- Proposed in 1998
 - Motivation: LSND excess of $\bar{\nu}_e$ in $\bar{\nu}_\mu$ beam (3.8σ)
 - Designed to test the oscillations signal of LSND with different systematics
- Data Taking (2002-2014)
 - Neutrino mode, 6.46×10^{20} POT
 - Antineutrino mode, 11.27×10^{20} POT
 - Beam Dump mode, 1.86×10^{20} POT
- Collaboration:
 - 15 -17 U.S. Institutions,
 - +1 UK (Imperial College) + 1 Latin American (UNAM)
 - Varied between ~45 to ~90 people throughout the years
- Produced
 - 25 refereed publications (>3800 citations in INSPIRE)
 - 18 PhD theses
- Currently: DM search over Beam Dump data
 - Motivation: Test dark-photon models for DM with vector mediator (V) and DM particle χ

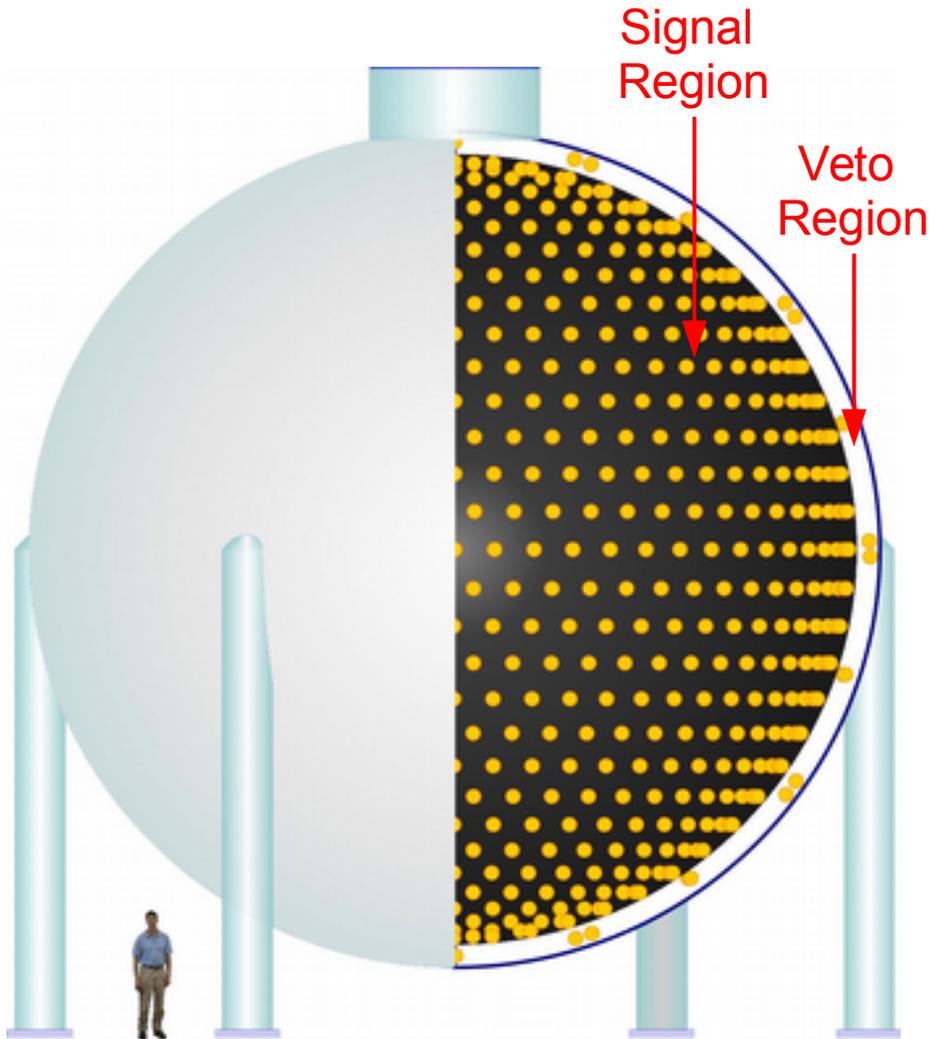
Mini-Booster Neutrino Experiment



- L/E similar to LSND
MiniBooNE ~ 500 m / ~ 500 MeV
LSND ~ 30 m / 30 MeV
- Horn focused neutrino beam (p+Be)
Horn increases $\nu/\bar{\nu}$ flux by ~ 6
Polarity \rightarrow neutrinos or anti-neutrinos
- Cherenkov Detector
800 ton mineral oil



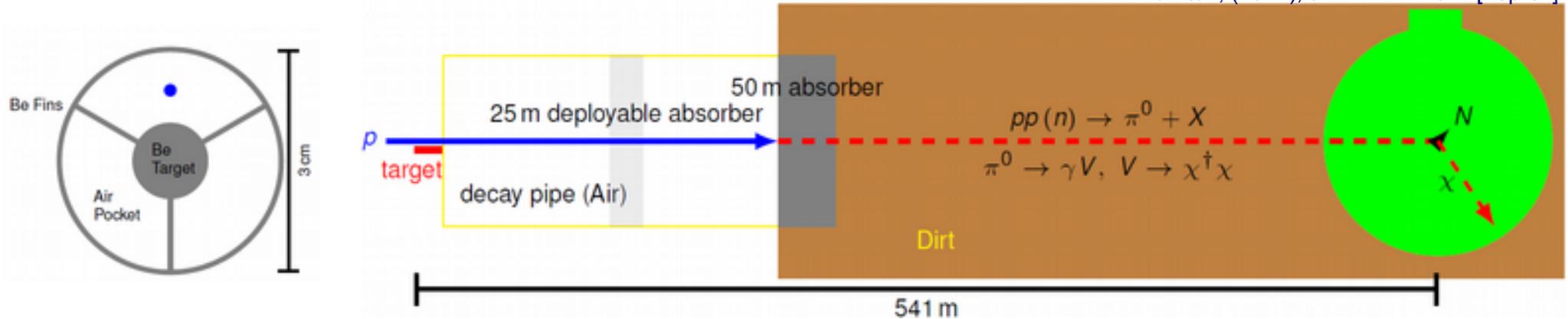
MiniBooNE Detector



- 800 tons of mineral oil acting as a Cherenkov/scintillator Detector.
- 1280 inner and 240 veto PMTs.
- Running for 10 years
 - ν mode: 6.5×10^{20} POT
 - $\bar{\nu}$ mode: 11.3×10^{20} POT
- ***The detector is well Understood***
- Ran 10 months 2013-2014
 - off-target mode: 1.86×10^{20} POT

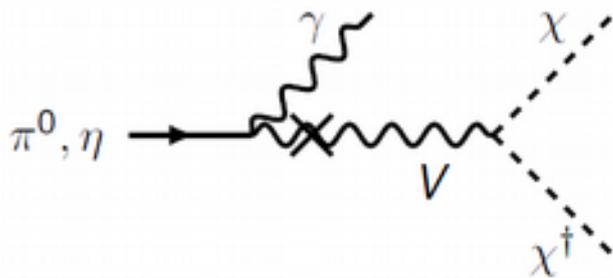
MiniBooNE Beam Dump Mode

R. T. Thornton, (2014), arXiv:1411.4311 [hep-ex].



- Charged Mesons absorbed in beam dump before decay \Rightarrow reduce ν flux.
- Neutral mesons decay in flight \Rightarrow produce boosted dark matter

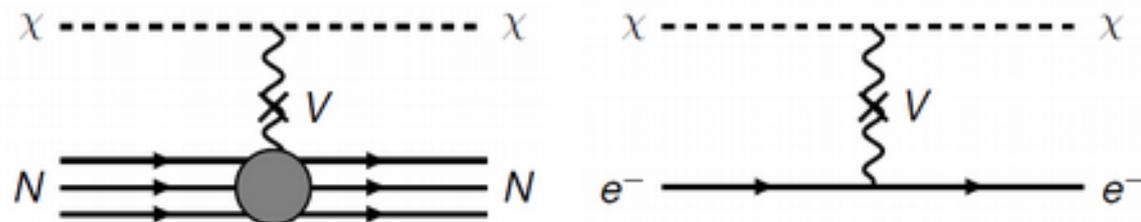
Production



Dark Photon theory with a vector mediator (V) and a dark matter particle (χ).

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

Interactions in detector



Similar to ν Neutral-Current elastic scattering (NCEl)

Summary of MB results

- **Nue Appearance:** [[PRL 110 161801 \(2013\)](#)]
 - Antineutrino mode excess (2.8σ): energy spectrum compatible with LSND signal.
 - Neutrino mode excess (3.4σ): energy spectrum marginally compatible with LSND.
 - In simultaneous $\nu / \bar{\nu}$ fit in a 3+1 model excess is 3.6σ . [[arXiv:1207.4809](#)]

- **Numu Disappearance** [[PRD 85 032007 \(2012\)](#), [PRD 86 0520009 \(2012\)](#)]
 - Limits for SBL numu, numubar disappearance (jointly with SciBooNE)
 - Strong tension with appearance results in global fits.

- **Cross-section Measurements**
 - “Measurement of antineutrino Neutral-Current Elastic Differential Cross Section”, [PRD 91 012004 \(2015\)](#)
 - “First Measurement of the ν_{μ} Double Differential Charged-Current Quasi-Elastic Cross Section”, [PRD 88 032001 \(2013\)](#)
 - “Measurement of Neutrino-Induced $CC\pi^+$ Production Cross Sections on mineral oil at $E_{\nu} \sim 1$ GeV”, [PRD 83 052007 \(2011\)](#)
 - “Measurement of nm-induced $CC\pi^0$ production cross sections on mineral oil at $E_{\nu} \in 0.5-2$ GeV”, [PRD 83 052009 \(2011\)](#)
 - “Measurement of the neutrino NC-Elastic differential cross section”, [PRD 82, 092005 \(2010\)](#)
 - “First Measurement of the ν_{μ} CCQE double differential cross section”, [PRD 81, 092005 \(2010\)](#)
 - “Measurement of ν_{μ} and $\bar{\nu}_{\mu}$ induced NC π^0 production cross sections in mineral oil at $E_{\nu} \sim O(1\text{GeV})$ ”, [PRD 81, 013005 \(2010\)](#)
 - “Measurement of the ν_{μ} CC π^+ to quasi-elastic cross section ratio in mineral oil in a 0.8 GeV n beam”, [PRL 103, 081801 \(2009\)](#)
 - “First observation of coherent π^0 production in n-Nucleus interactions with $E_{\nu} < 2$ GeV”, [PL B664, 41 \(2008\)](#)
 - “Measurement of ν_{μ} Quasi-Elastic Scattering on Carbon”, [PRL 100, 032301 \(2008\)](#)
 - 10 cross section measurements. Many firsts in time and quality.
 - Observed discrepancies with models of ν interactions with nuclei
 - first evidence for multinucleon effects.

- **DM search results expected this year.**
 - Stay tuned!



MiniBooNE Collaboration

University of Alabama, Tuscaloosa, Alabama, USA
 Argonne National Laboratory, Argonne, Illinois, USA
 University of Cincinnati, Cincinnati, Ohio, USA
 University of Colorado, Boulder, Colorado, USA
 Columbia University, New York, New York, USA
 Fermi National Accelerator Laboratory, Batavia, USA
 University of Florida, Gainesville, Florida, USA
 Indiana University, Bloomington, Indiana, USA
 Los Alamos National Laboratory, Los Alamos, New Mexico, USA
 Louisiana State University, Baton Rouge, Louisiana, USA
 Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México
 University of Michigan, Ann Arbor, Michigan, USA
 Saint Mary's University of Minnesota, Winona, Minnesota, USA
 Yale University, New Haven, Connecticut, USA
 Center for Neutrino Physics, Virginia Tech, Blacksburg, Virginia, USA
 Imperial College London, London, United Kingdom

MiniBooNE- Dark Matter Collaboration

University of Alabama, Tuscaloosa, Alabama, USA
 University of Chicago, Chicago, Illinois, USA,
 University of Cincinnati, Cincinnati, Ohio
 Columbia University, New York, New York, USA
 Fermi National Accelerator Laboratory, Batavia, IL, USA
 University of Florida, Gainesville, Florida
 Indiana University, Bloomington, Indiana, USA
 Los Alamos National Laboratory, Los Alamos, New Mexico, USA
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México
 University of Michigan, Ann Arbor, Michigan, USA
 University of Victoria, Victoria, BC, Canada
 Queen Mary University of London, London, UK
 Virginia Tech, Blacksburg, Virginia, USA
 University of Washington, Seattle, Washington, USA
 Saint Mary's University of Minnesota, Winona, Minnesota, USA

Latin American collaborators

Brazil

- **Fernanda G. García**

- 2000-2004: Particle Physics Division, FNAL
- 2004-Present: Accelerator Division, FNAL
- MiniBooNE and MiniBooNE-DM



Mexico

- **Alexis A. Aguilar-Arévalo**

- 2002-2007, (GS) Columbia University, NY
- 2009-Present, (Scientist) ICN-UNAM, Mexico City
- MiniBooNE and MiniBooNE-DM

- **Iker L. de Icaza Astiz**

- 2012-2016 (UG) ICN-UNAM, Mexico City
- MiniBooNE-DM



Brazilian Contributions

F.G. Garcia @ PPD (2000-2004)



- Responsible for organizing/coordinating/developing schedule for the MiniBooNE PMT's preparation phase.
- Responsible for the MiniBooNE Detector – installation phase and running period.
- Responsible for MiniBooNE Operations – detector coordinator.
 - Presentation of first neutrino events observed by MiniBooNE detector – Sept/2002.
- Participated on the determination of pedestal signals for the PMT readout electronics.
- Participated on the cross-sections working group.



Alexis A. Aguilar-Arévalo (ICN-UNAM)



Neutrinos Latin America Workshop

27-28 April 2016

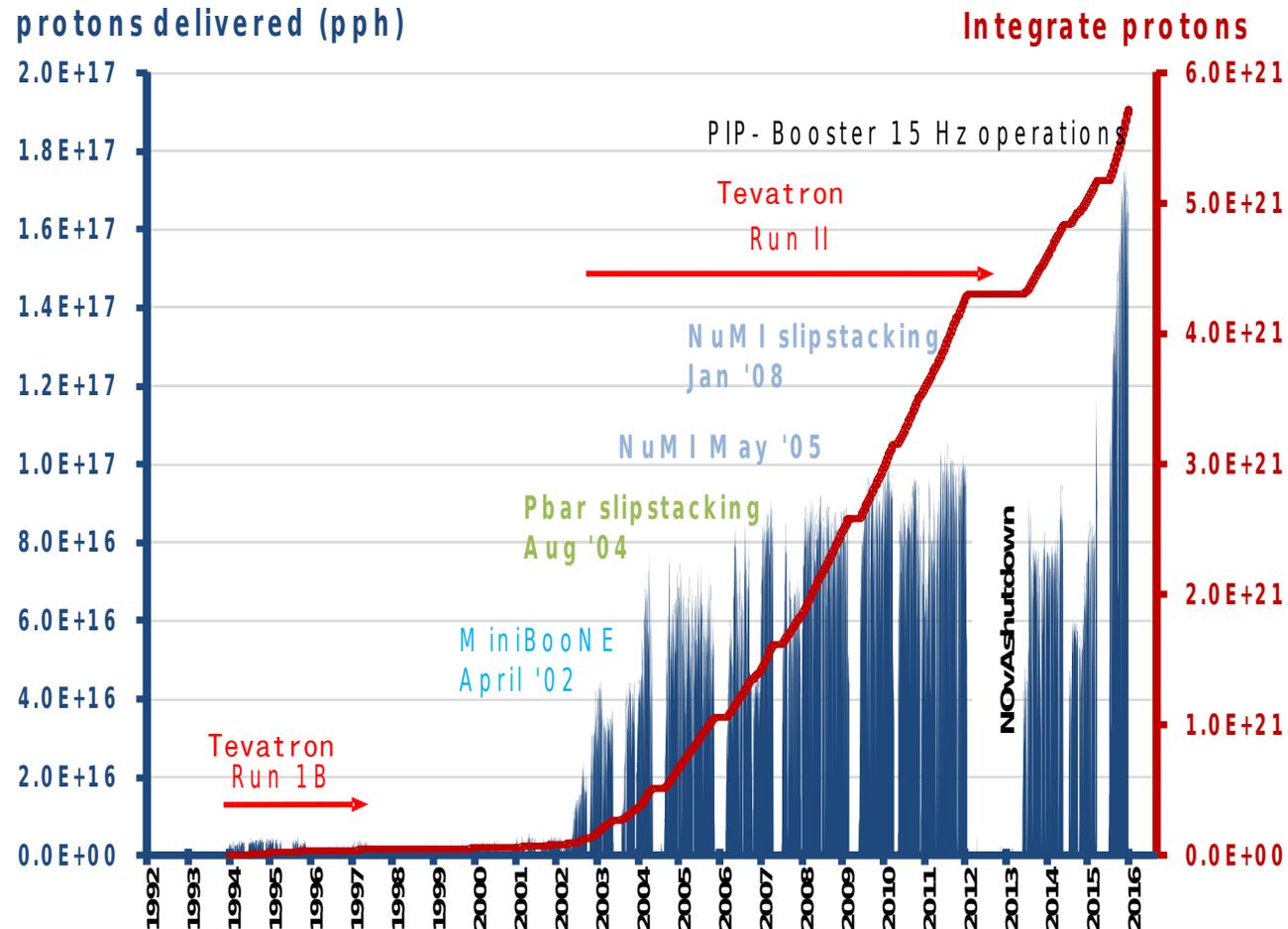
Fermilab

Brazilian Contributions

F.G. Garcia @ AD (2004-Present)



- Head of the Booster 400 MeV transfer line (2004-2008)
 - **Proton Plan**: Responsible for redesign, construction, installation and commissioning of the new Booster injection line.
- Head of the FNAL Linac Group (2008-Present)
- L2 manager for **PIP** Linac Projects (2011-Present)
- L2 manager for **PIP-II** SRF Linac (2015-Present)



Ideas for accelerator enhancements targeted at improved beam quality and reliability for users

– all initiated by the MiniBooNE experiment

Mexican Contributions

A. A.-A. @ Columbia University, NY (2002-2007)

with the Columbia Neutrino Group (led by J. Conrad & M. Shaevitz)



- Early sensitivity estimates in neutrino and antineutrino mode.
- Co-developer of the $\nu_{\mu} \rightarrow \nu_e$ oscillation analysis based on *Boosted Decision Tree* (BDT) selection, and the combined ν_{μ} / ν_e fit (with J. Monroe and D. Schmitz).
- Developer of the combined BDT & TBL oscillation analysis (PhD Thesis).
- Responsible for NuMI events in MiniBooNE (trigger, initial simulation and analysis).

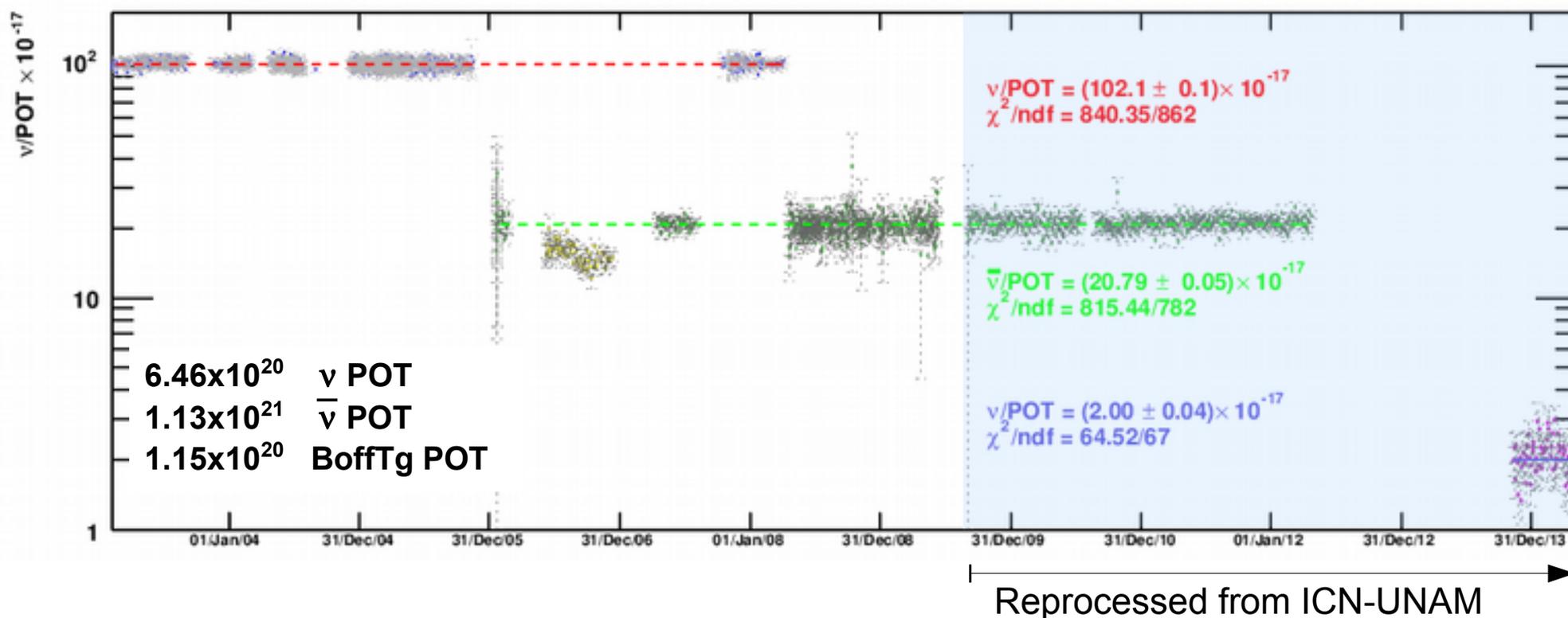
ICN-UNAM, México (2009-2015)

Instituto de Ciencias Nucleares
Universidad Nacional Autónoma de México



- Antineutrino/Beam Dump data reprocessing (2009-2015)
- Check of MB Data Releases for $\nu_e / \bar{\nu}_e$ appearance and ν_{μ} disappearance oscillation analyses [I. de Icaza and D.P. Méndez].
- Bench tests of new Fiber Optics timing system [I. de Icaza, 2012].
- Shifts at ICN-UNAM Remote Control Room (80 shifts, 640 hr).

Data reprocessing



- ICN-UNAM in charge of data reprocessing from 2009 to 2015.
 - *Antineutrino mode* (>1/2 of total antineutrino data collected)
 - *Beam Dump mode* (1.86×10^{20} POT)
 - *Random trigger (strobe) data for DM search analysis*
- Updating of scripts for usage of FNAL grid resources. Required frequent communication with FNAL grid support.
- Check stability of Nu/POT plot (above).

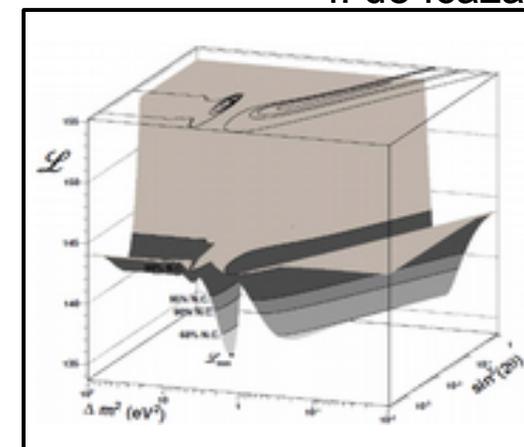
Data Release (DR) checks



$\nu_e / \bar{\nu}_e$ appearance oscillation analysis DR:

- Checked that public DR pages for all app. analyses produced results consistent with publications.
- Cross checks in parallel to the final oscillations analysis of 2013. Helpful in debugging of the analysis.
- Implementation of Frequentist Oscillation analysis (Feldman-Cousins) in a GPU with CUDA.
- BSc. Thesis of Iker de Icaza-Astiz (UNAM)
FERMILAB-BACHELORS-2013-01

I. de Icaza

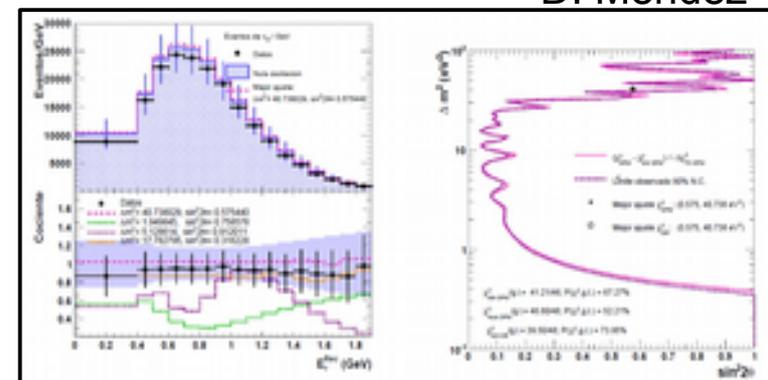


Joint MB+SB ν_μ disappearance analysis DR:

- A couple of errors in this DR were found and corrected.
- DR updated on 03/02/2016. ← **Is your work affected?**
- BS. Thesis of Diana P. Méndez-Méndez (*) (UNAM),
FERMILAB-BACHELORS-2015-01

(*) not a MB or SB collaborator

D. Méndez

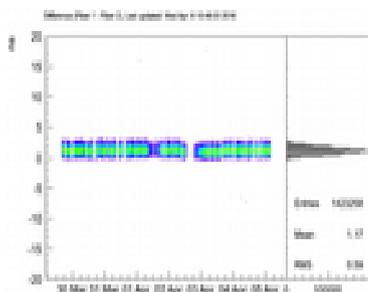


Other tasks



Bench testing of new Fiber Optics timing system

- Replacement of copper wire transmission line of the RWM beam timing system. Participated in installation and tests.
- Achieved stable <1 ns timing of p beam.
- Iker de Icaza-Astiz, srping 2012.



Shifts from ICN-UNAM RCR

- One of the few first international RCR's aproved at by FNAL AD controls (2009).
- 80 shifts (640 hr) [AA-A and ILdIA.]
- Allowed to comply with authorship quotas.



Summary

- MiniBooNE and MiniBooNE-DM have a small Latin American component.

BRAZIL: Fermilab



- 1 FNAL staff with many crucial contributions to MiniBooNE and the Booster Neutrino Beamline.

MEXICO:



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Universidad Nacional Autónoma de México



- 1 former GS at U.S. Institution. Continued participation at ICN-UNAM in México as Junior Researcher.
- 2 former undergraduates from UNAM. Moved to Uk to pursue PhD in neutrino physics (SBN exp and DUNE).
- ICN-UNAM is the only collaborating institution from Latin America.

- Helped pave the way for current SBN program at FNAL.

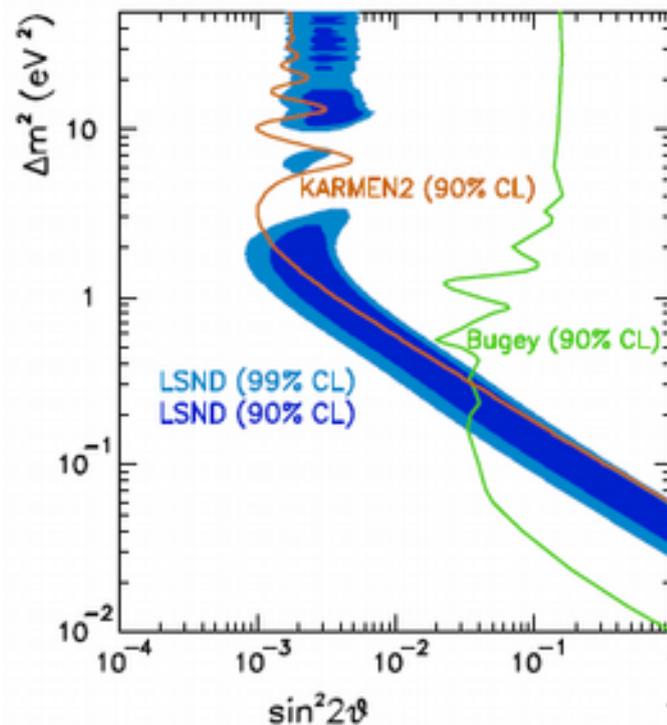
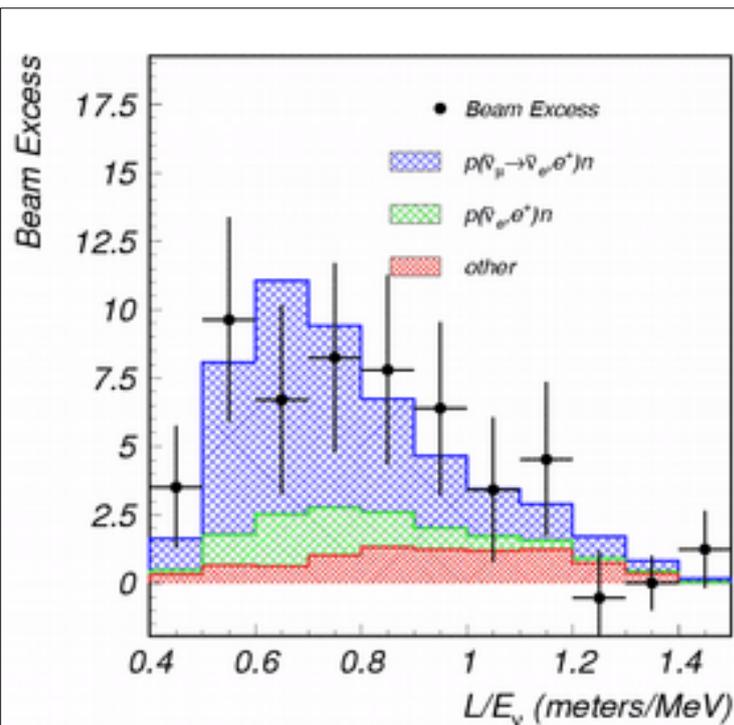


Thank you !

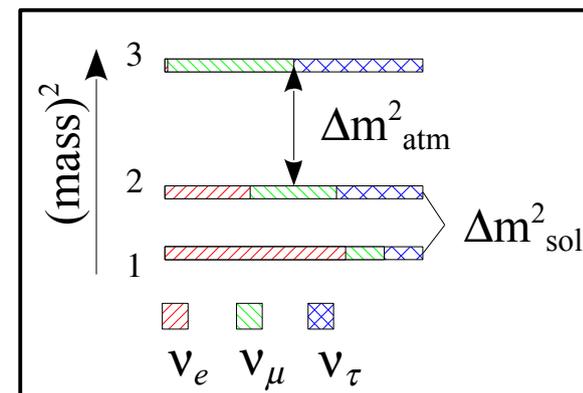
Backup Slides

MiniBooNE motivation: LSND

- LSND Experiment (Los Alamos, 1993-1998)
- Excess of $\bar{\nu}_e$ in $\bar{\nu}_\mu$ beam: $\text{Excess} = 87.9 \pm 22.4 \pm 6$ (3.8σ)
- Source is Pion decay at rest: $\pi^+ \rightarrow \mu^+ + \nu_\mu$, $\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$
 ν_e signal: Cherenkov light from e^+ with delayed n capture (2.2 MeV γ)
- Interpreted as 2 ν oscillations: $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = \sin^2 2\theta \sin^2(1.27 \Delta m^2 L/E)$
 (equivalent to 3+1 model) $= (0.245 \pm 0.067 \pm 0.045)\%$



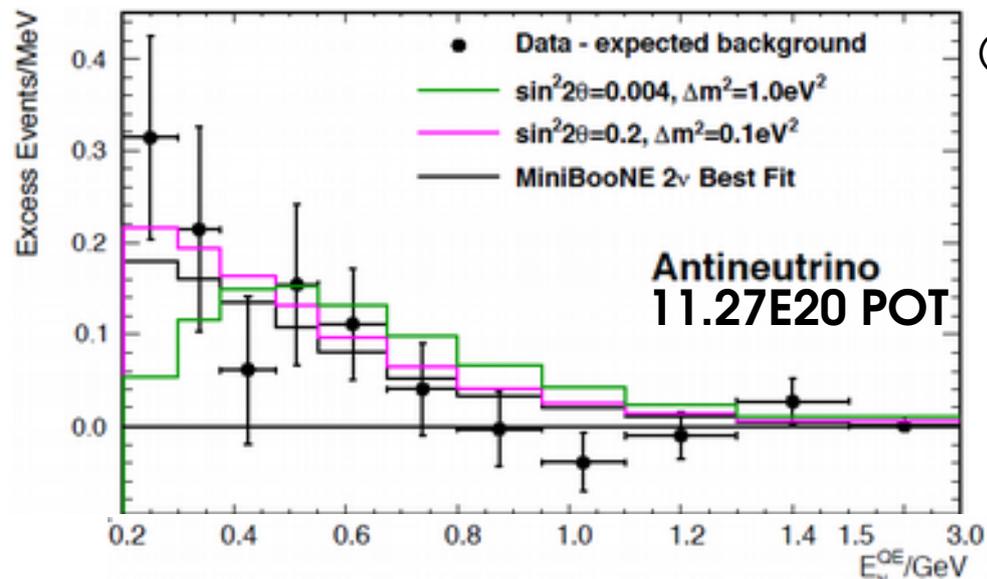
In conflict with other
osc. exp's if only 3 ν 's.



$$\Delta m_{\text{LSND}}^2 \neq \Delta m_{\text{atm}}^2 + \Delta m_{\text{solar}}^2$$

Final oscillations ($\bar{\nu}_e$ app.) results

PRL 110,161801 (2013)



(200-1250 MeV):

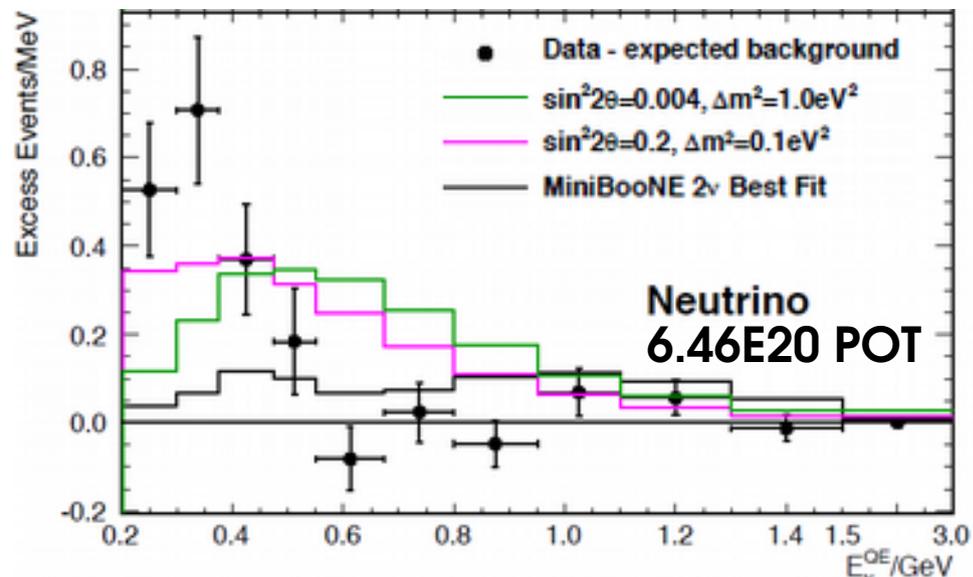
$$\chi^2/ndf \text{ (bf)} = 5/7$$

$$\text{Prob(bf)} = 66\%$$

$$\chi^2/ndf \text{ (null)} = 16.6/8.9$$

$$\text{Prob(null)} = 5.4\%$$

Excess (200-1250 MeV): 78.4 ± 28.5 (2.8σ)



(200-1250 MeV):

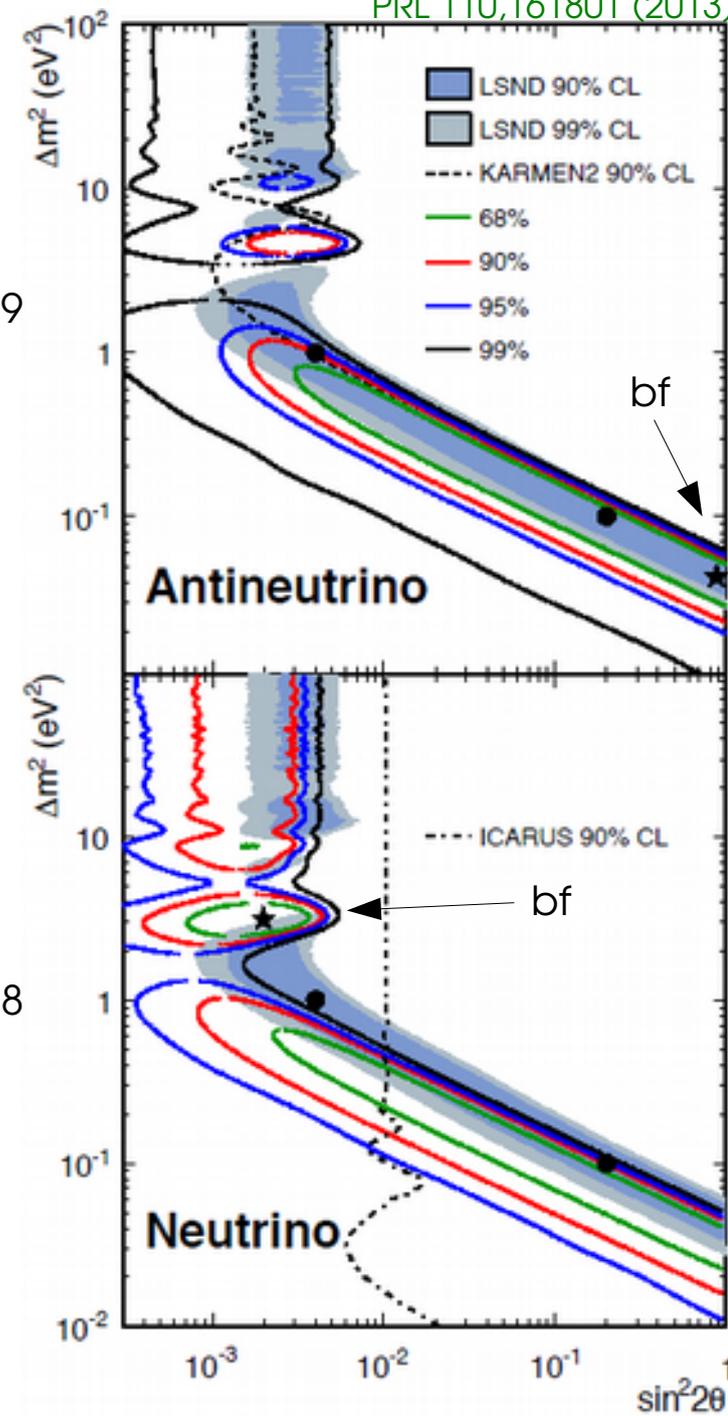
$$\chi^2/ndf \text{ (bf)} = 13.2/6.8$$

$$\text{Prob(bf)} = 6.1\%$$

$$\chi^2/ndf \text{ (null)} = 22.8/8.8$$

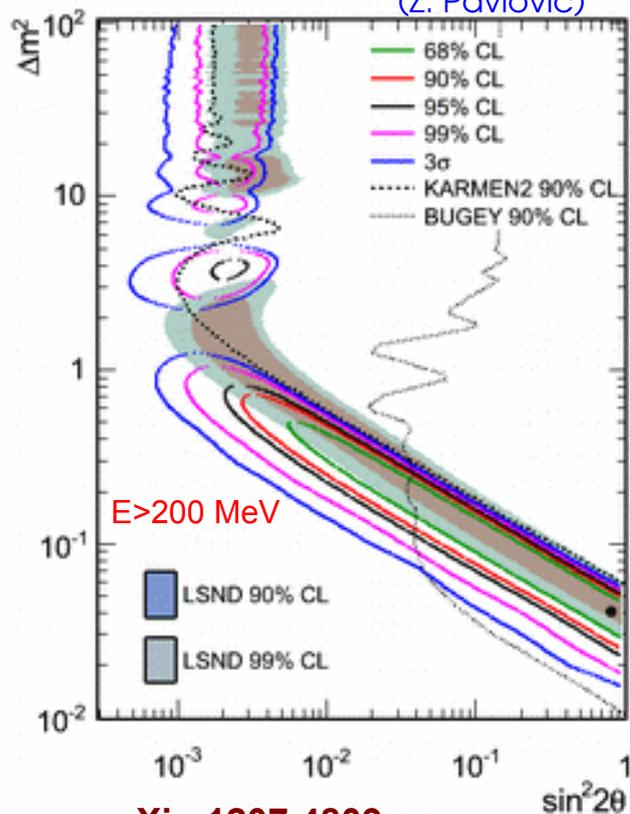
$$\text{Prob(null)} = 0.5\%$$

Excess (200-1250 MeV): 162.0 ± 47.8 (3.4σ)



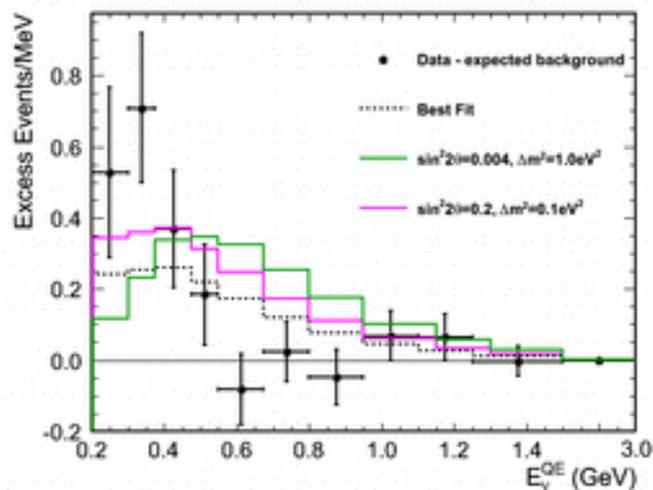
Simultaneous 3+1 fit to ν and anti- ν data

(Z. Pavlovic)

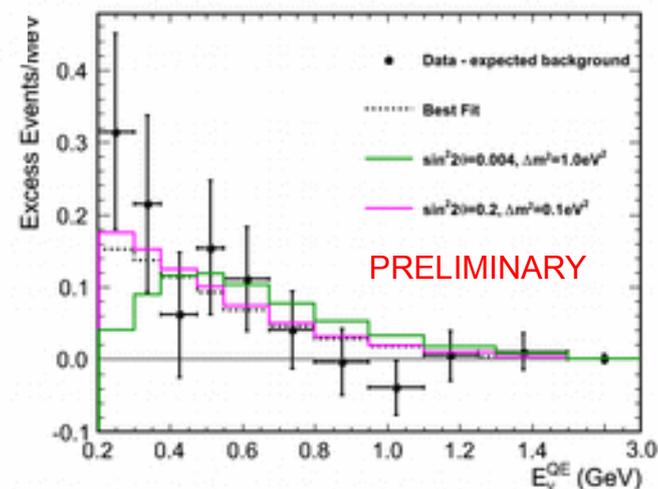


arXiv:1207.4809

- WS accounted for properly
- Construction of correlated systematic error matrix
- $E > 200$ MeV BF preferred at 3.6σ **over null**.



Simultaneous fit ($E > 200$ MeV) with fully-correlated systematic to entire MB neutrino and anti-neutrino data

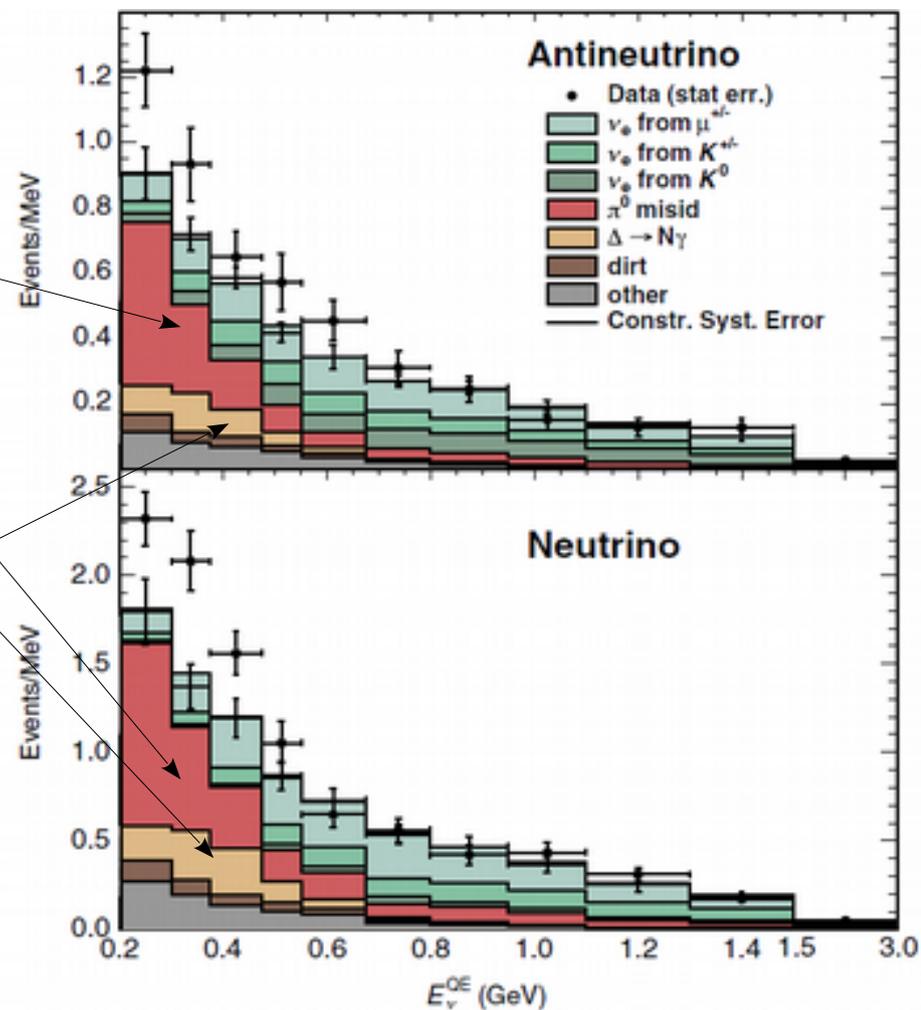


Total Excess: $240.3 \pm 34.5 \pm 52.6$

combined	$E > 200$ MeV	$E > 475$ MeV
$\chi^2(\text{null})$	42.53	12.87
Prob(null)	0.1%	35.8%
$\chi^2(\text{bf})$	24.72	10.67
Prob(bf)	6.7%	35.8%

What we know about the low-E excess

- Not quite the same in nu/antineu modes
- Not a stat fluctuation
- Unlikely to be intrinsic ν_e , small bkg at low E
- NC π^0 background dominates
 - Heavily constrained by NC π^0 *in situ* measurement
- Region where single γ can contribute
- MB ties $\Delta \rightarrow N\gamma$ expected rate to be 1% of measured NC π^0 rate
 - Number of theory calculations for various single γ processes: R. Hill, arXiv:0905.0291
Jenkins & Goldman, arXiv:0906.0984
Serot & Zhang, arXiv:1011.5913
 - All find total cross section within 20% of MB
 $\sim 5 \times 10^{-42} \text{ cm}^2/\text{N}$
 - Would need nearly 300% change



MicroBooNE (LAr) experiment will study this excess

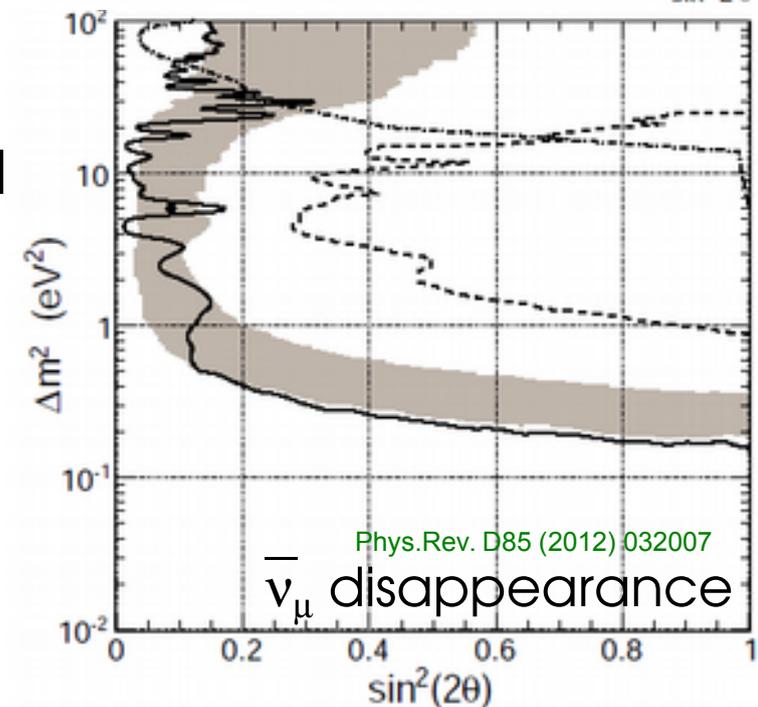
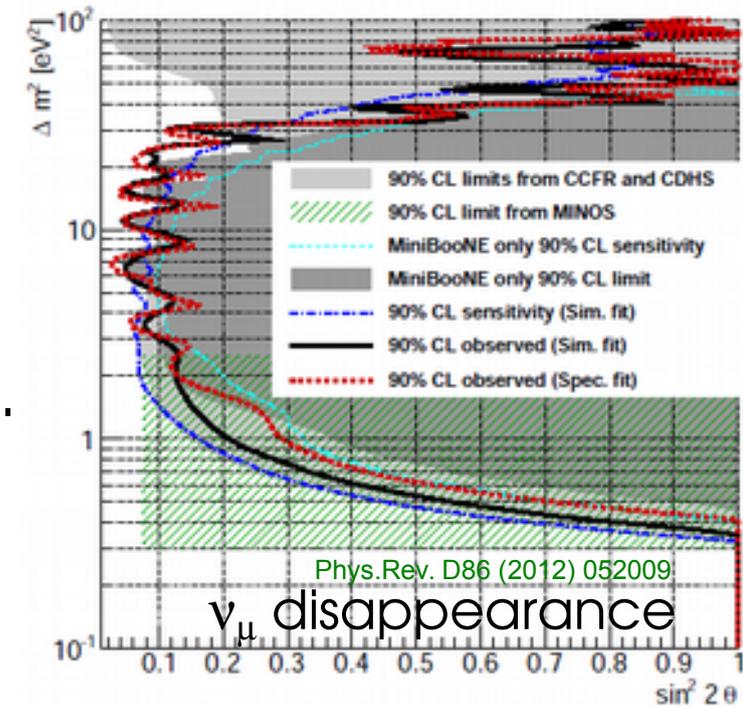
ν_μ & $\bar{\nu}_\mu$ disappearance

Not yet observed at short baselines.

MiniBooNE+SciBooNE performed joint ν_μ & $\bar{\nu}_\mu$ disappearance searches obtaining null results.

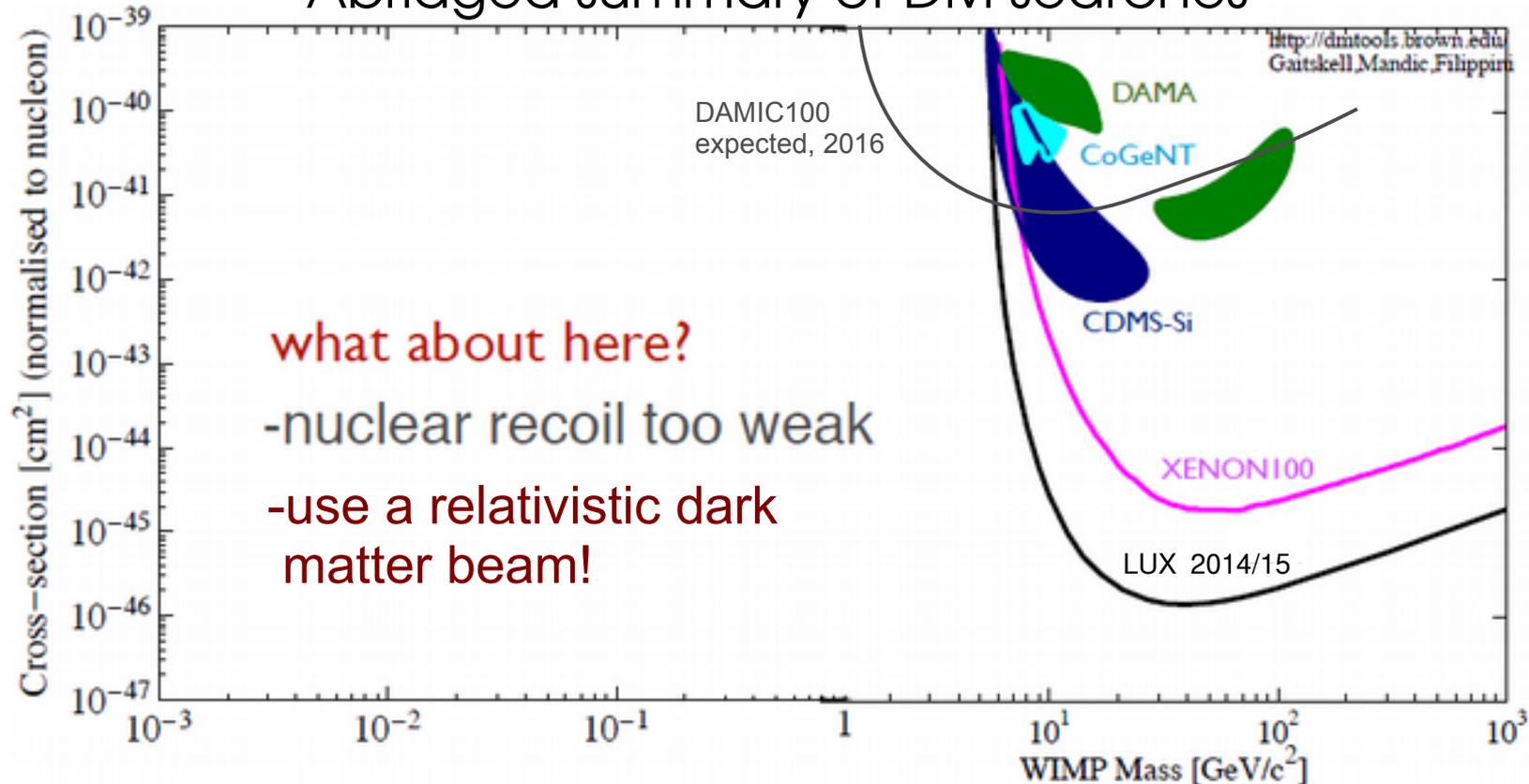
These results are in tension with appearance evidence from LSND and MB- $\bar{\nu}_\mu$. (expect 5 -10% ν_μ , $\bar{\nu}_\mu$ disappearance).

Including the disappearance results in global fits (3+1, 3+2, 3+3) with LSND+MB data
 → tension btwn appearance and disappearance data sets.



MiniBooNE-DM motivation

Abridged summary of DM searches



- Recent theoretical work highlights light (sub-GeV) WIMP's as viable DM candidates

B. Batell, M. Pospelov, A. Ritz, Phys.Rev. D80, 095024 (2009)
 P. deNiverville, D. McKeen, A. Ritz, Phys.Rev. D86, 035022 (2012)

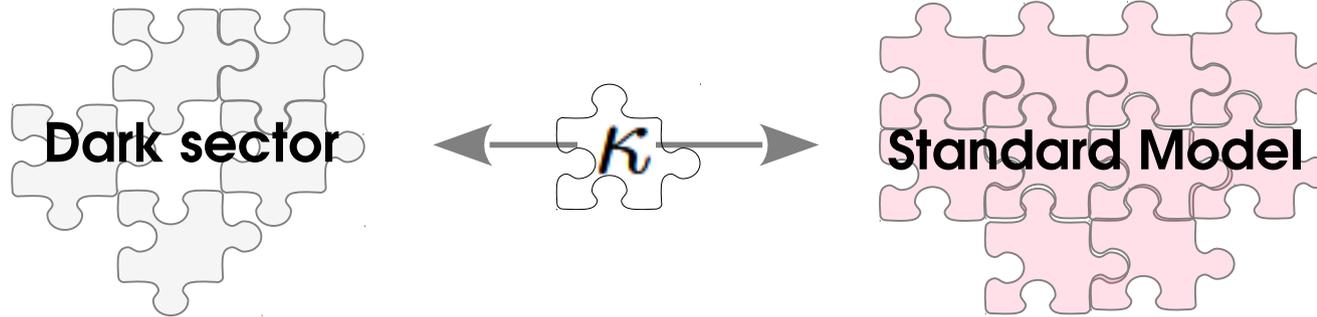
MB
 collaborators

- Idea: **relativistic WIMP beam + well understood neutrino detector.**
- MiniBooNE is pioneering in this type of DM search.

Light Dark Matter

- A minimal extension to the Standard Model:

Secluded $U(1)'$ sector with weak admixture to photons ($SB < 1 \text{ GeV}$)



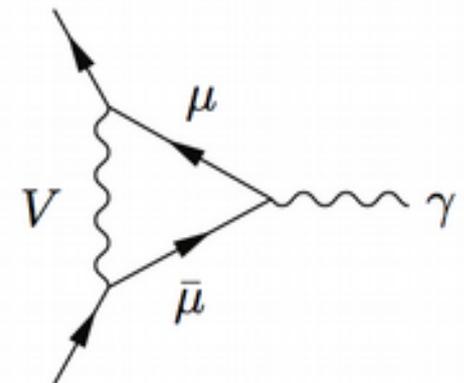
$$\mathcal{L}_{V,\chi} = |D_\mu \chi|^2 - m_\chi^2 |\chi|^2 - \frac{1}{4} V_{\mu\nu}^2 + \frac{1}{2} m_V^2 V_\mu^2 + \kappa V_{\mu\nu} F^{\mu\nu} + \dots$$

$$D_\mu = \partial_\mu - ie' V_\mu, \quad e' = \sqrt{4\pi\alpha'}$$

4 parameters: $m_\chi, m_V, \kappa, \alpha'$

B. Batell, M. Pospelov, A. Ritz, Phys.Rev. D80, 095024 (2009)
P. deNiveville, D. McKeen, A. Ritz, Phys.Rev. D86, 035022 (2012)

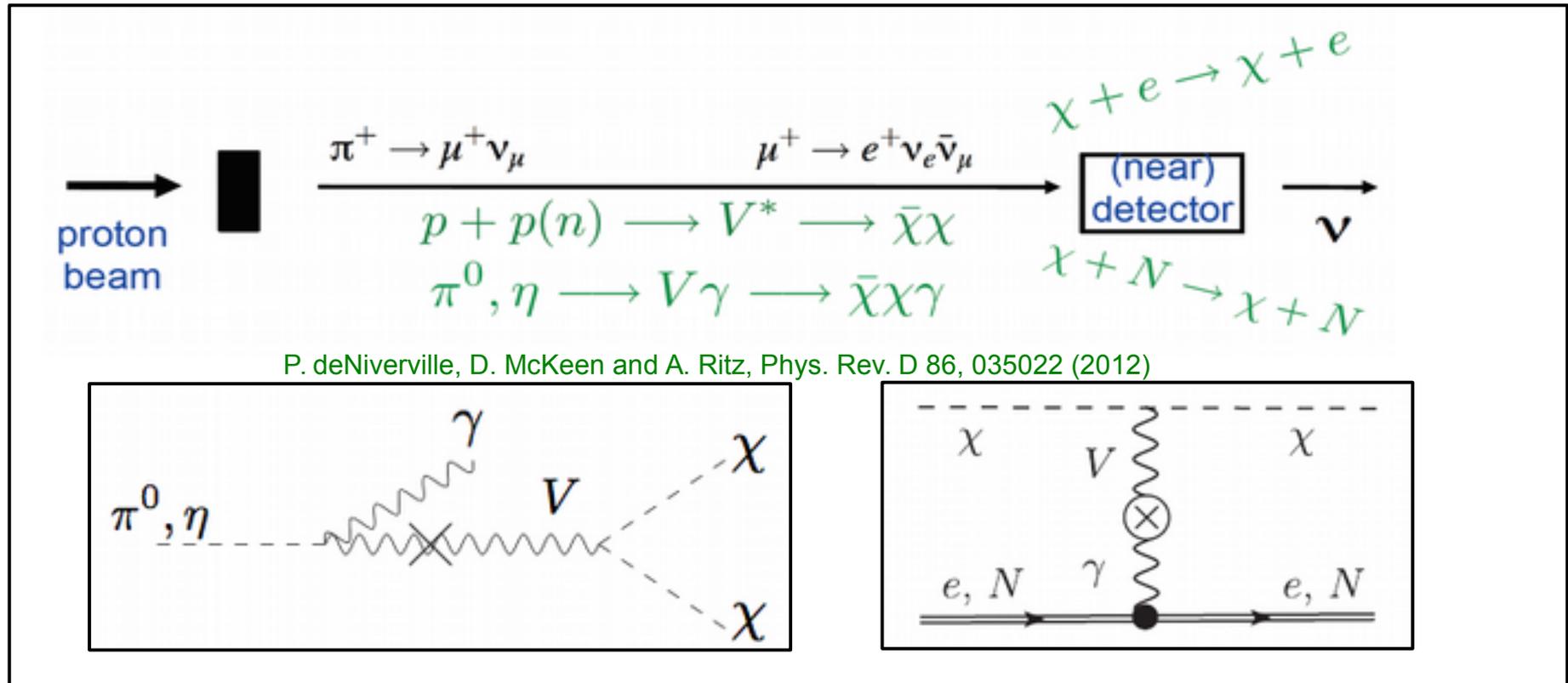
- New mediators increase annihilation cross section of the dark matter to give the correct relic density. Also mediate interactions with the SM
- Mediator with mass $O(10-10^3 \text{ MeV})$ can alleviate $(g-2)_\mu$ 3σ discrepancy (theo vs. exp).



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

How to look for this?

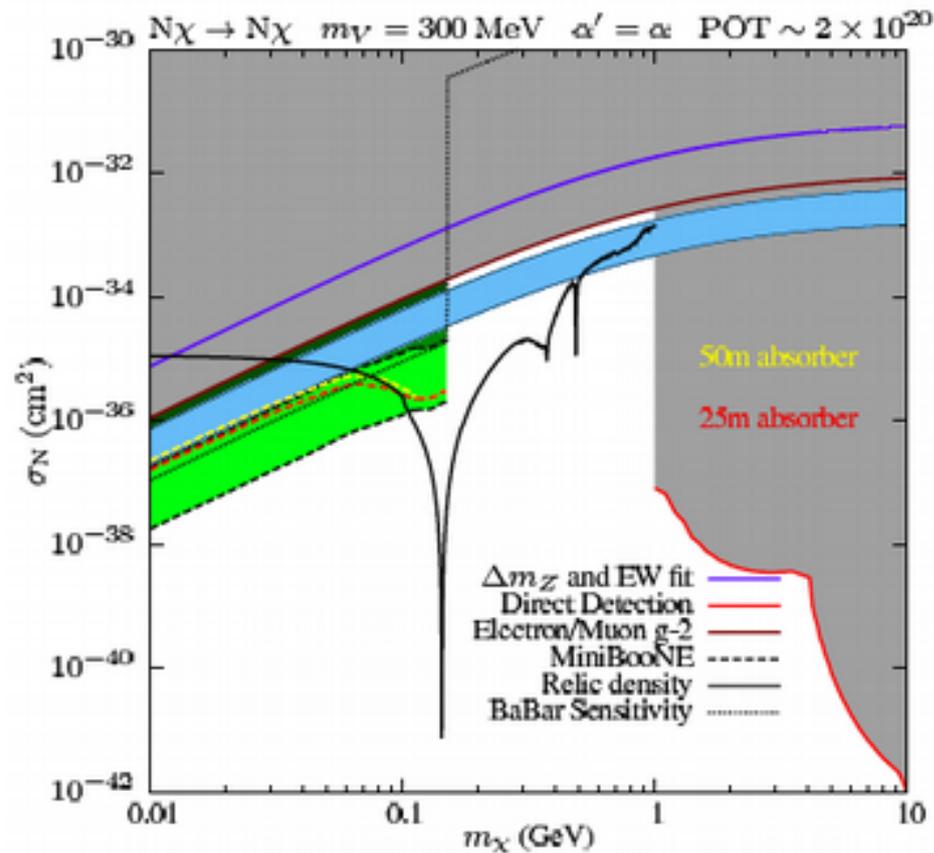
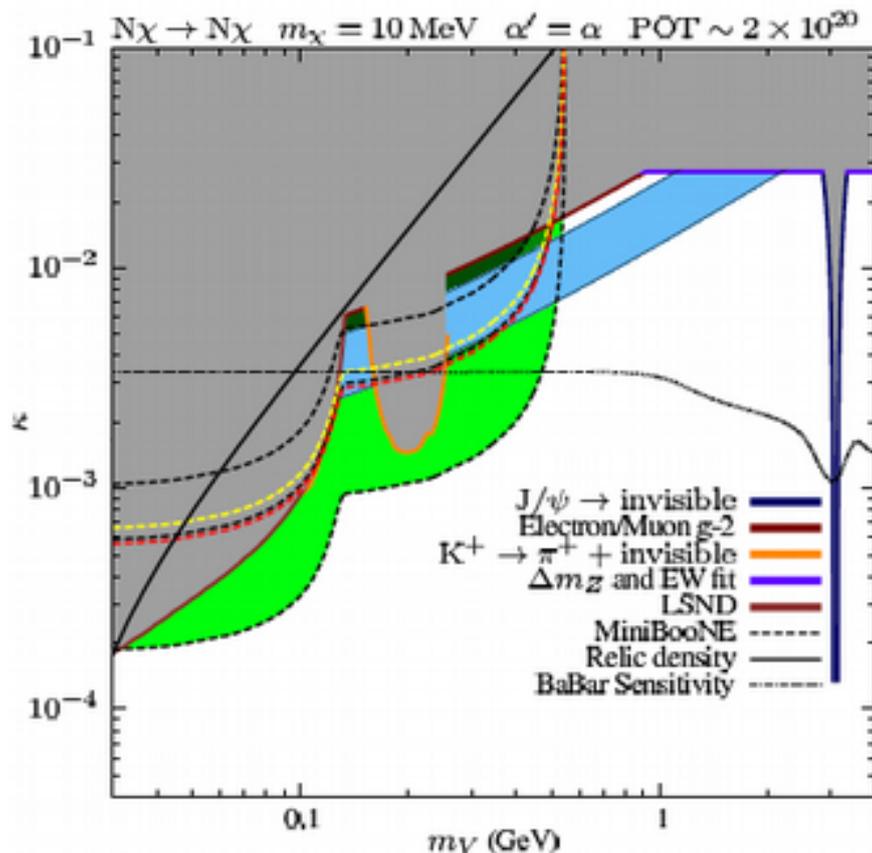
Fixed target high intensity beams with a large near detector with a relatively low energy threshold.



Ideal setup: MiniBooNE experiment at Fermilab

MiniBooNE: Beam-off-target mode

WIMP-nucleon scattering capabilities



Plots by P. deNiverville, UVictoria

Outlook of Light WIMP searches:

Stage 1: Operate in tandem with existing experiments.

Stage 2: Dedicated searches with existing (future) neutrino exps.

Stage 3: Dedicated experiments for Light WIMP searches.