Neutrino and Dark Matter in Mexico (experimental activity)

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ICN-UNAM

4th International Workshop for the Design of the ANDES Underground Laboratory,
Unidad de Seminarios Dr. Ignacio Chávez, UNAM
January 30-31, 2014

Outline:

Mexican participation in experiments with:

- Neutrinos
  - MiniBooNE
  - MINERvA
  - Plans for reactor monitoring with ν's
- Dark Matter
  - MiniBooNE-DM
  - DAMIC

Neutrinos

- Neutrinos have masses.
- Implication of neutrino oscillation experiments:

  (solar, reactor, atmospheric, LBL- accelerator)

  - Mar 2012: measurement of θ_{13}. (→ *See J.P Ochoa's Talk*)
  - Most experiments consistent with a de 3 ν's
  - ¿absolute mass scale? ¿mass hierarchy? ¿CP viol? ¿Dirac/Majorana?
- Anomalous results from SBL experiments:

  LSND, MiniBooNE, radioactive source (Ga), reactor anomaly

  May point to the existence of more than 3 neutrinos
- Strong program of cross section measurements around ~1 GeV underway.
- Use of SBL neutrino experiments for certain DM searches
- Technological applications of neutrinos:

  reactor neutrino monitoring

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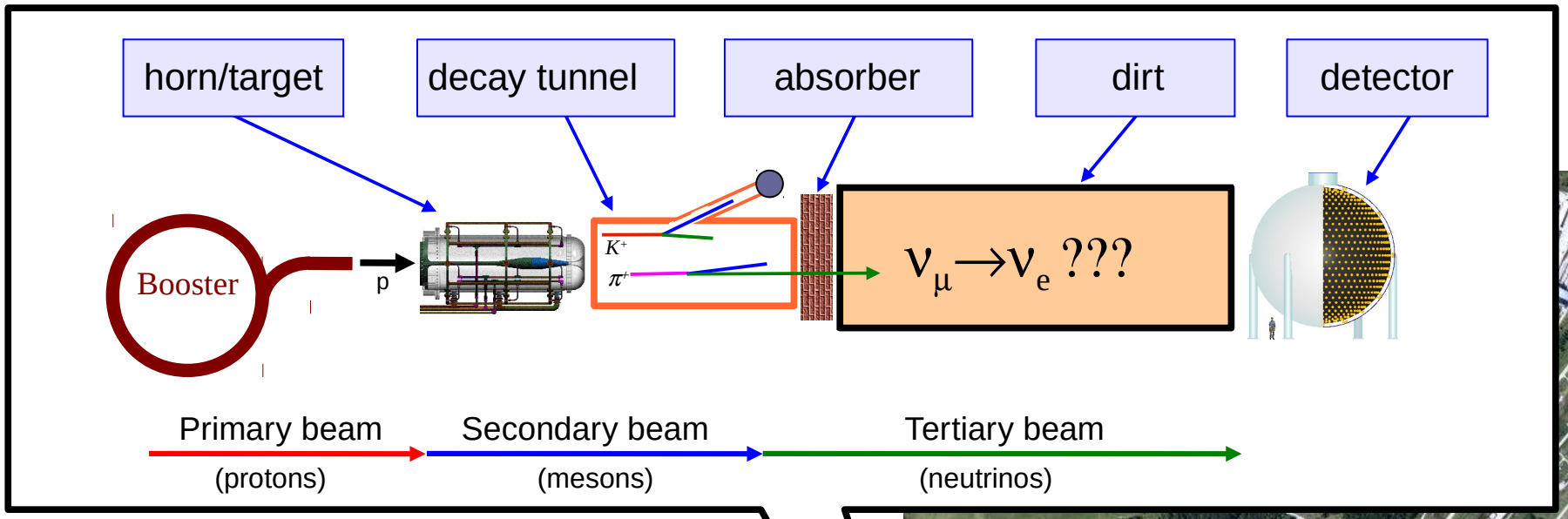
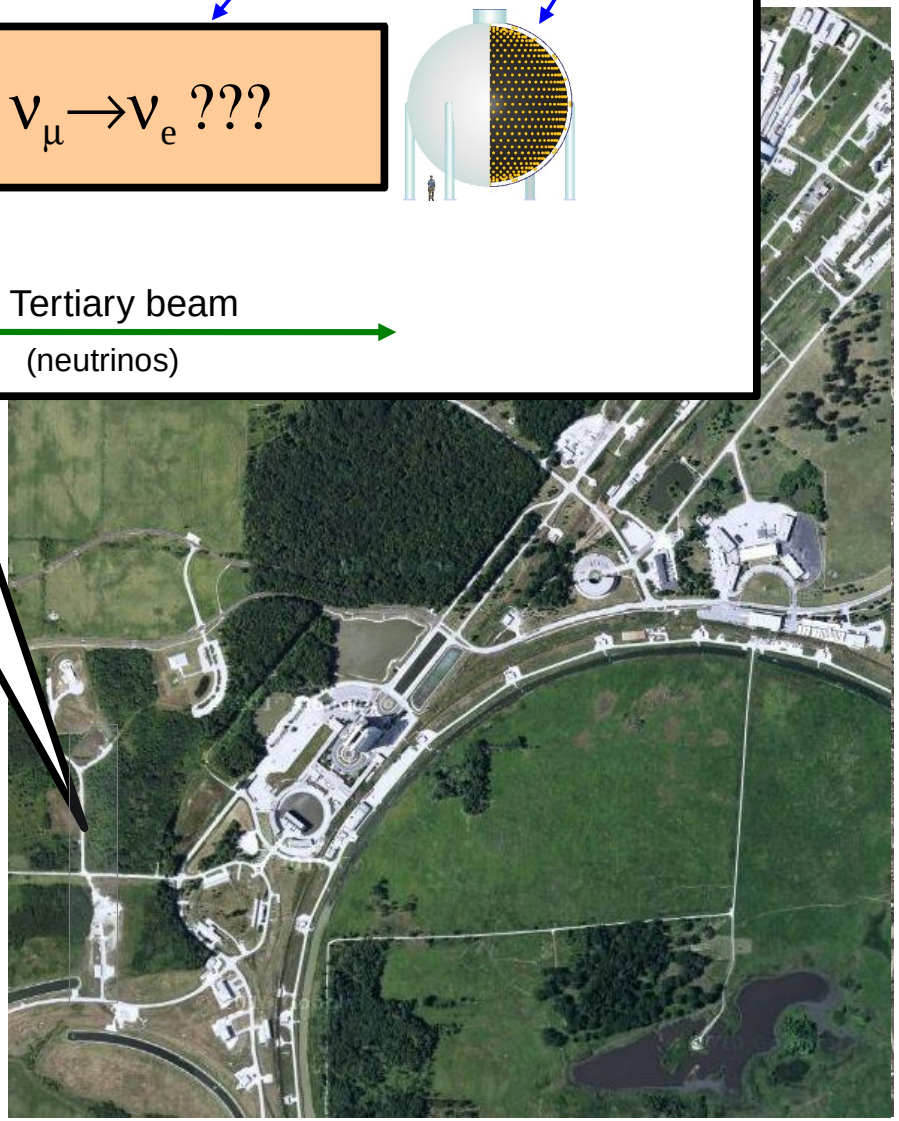
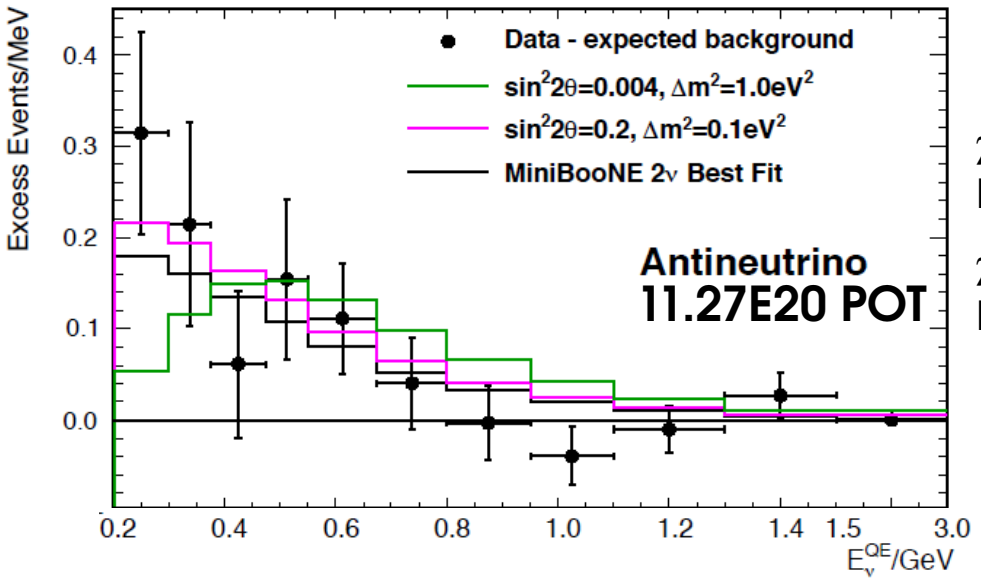
Mini-Booster Neutrino Experiment





- *L/E* similar to LSND (3.8 σ) app signal
  - MiniBooNE ~500 m /~500 MeV
  - LSND ~30m / 30 MeV
- Horn focused neutrino beam (p+Be)
  - **Horn increases nu/nubar flux by ~6**
  - **Polarity → neutrinos or anti-neutrinos**
- Cherenkov Detector
  - 800 ton mineral oil

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

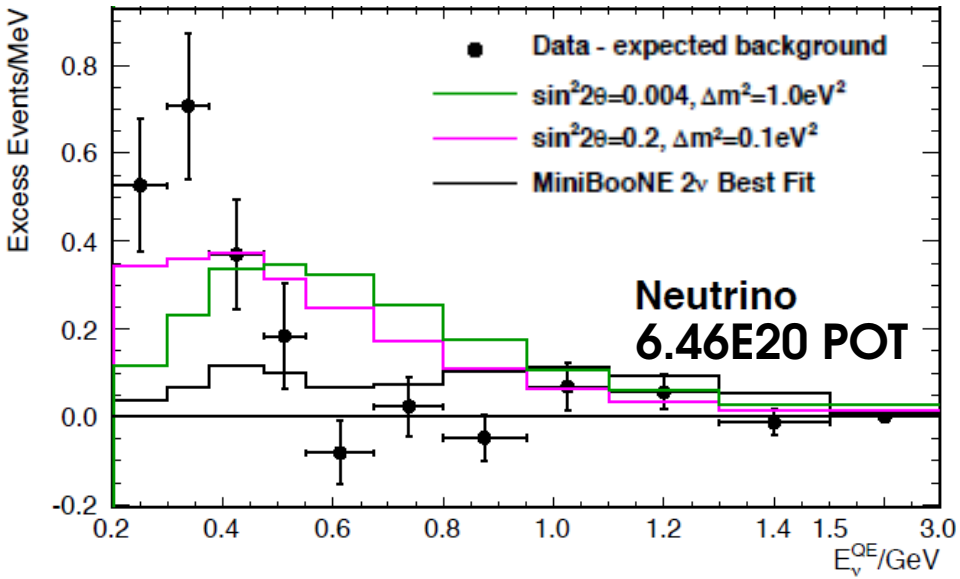


(200-1250 MeV):

χ^2/ndf (bf)=5/7
Prob(bf) = 66%

χ^2/ndf (null)=16.6/8.9
Prob(null) = 5.4%

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



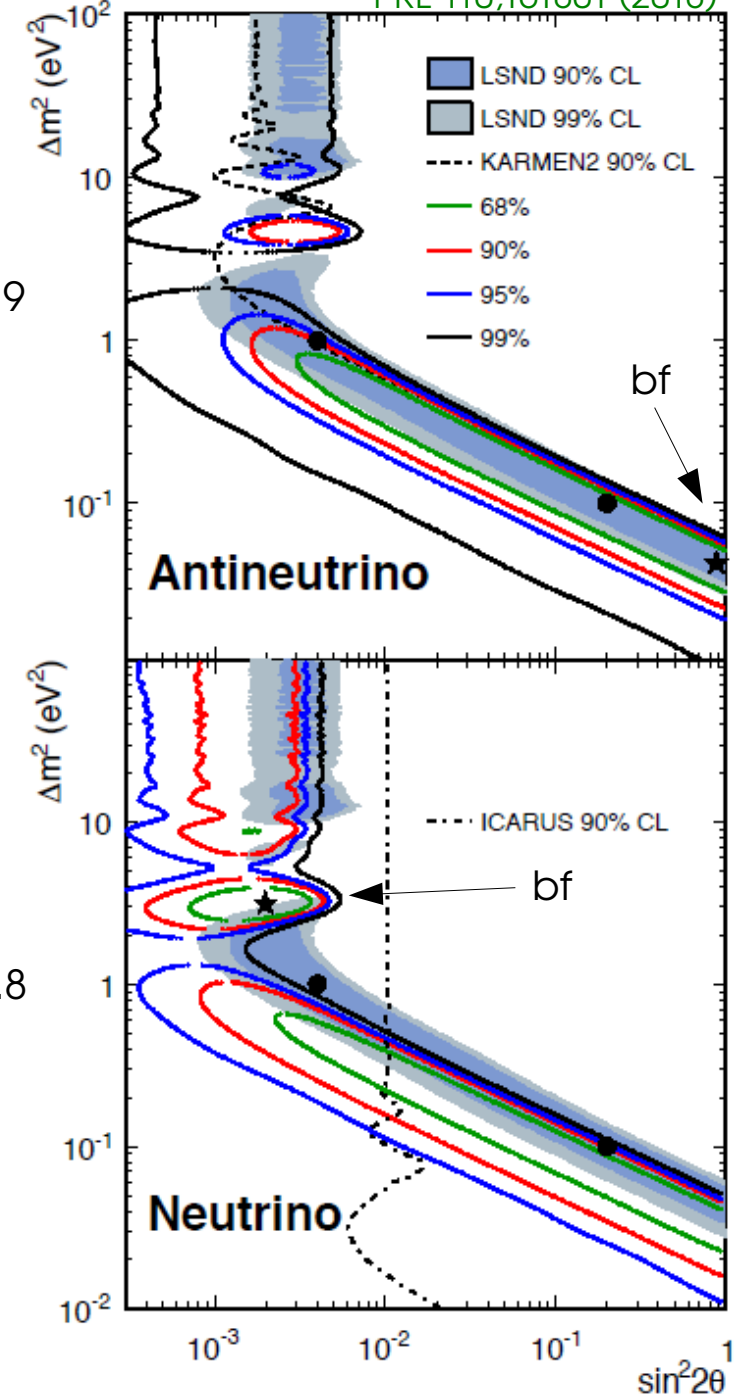
(200-1250 MeV):

χ^2/ndf (bf)=13.2/6.8
Prob(bf) = 6.1%

χ^2/ndf (null)=22.8/8.8
Prob(null) = 0.5%

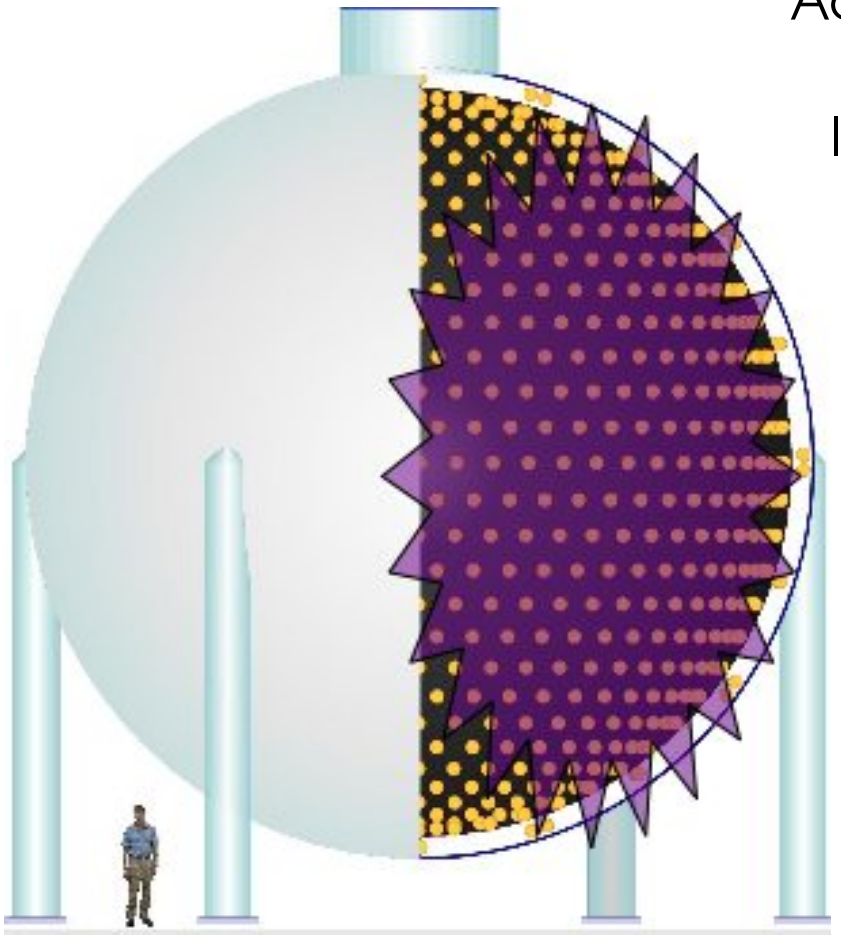
Excess (200-1250 MeV): 162.0 ± 47.8 (3.4 σ)

PRL 110,161801 (2013)



MiniBooNE+

arXiv:1210.2296 (2012)



Add scintillator to MiniBooNE oil:

Increase capability to tag neutron captures:

$$n + {}^{12}C \rightarrow {}^{12}C^{*} \rightarrow \gamma(2.2MeV)$$

Current n-tag → 5 PMTs
MB+ Scintillator→ 25 PMTs (reconstructible!)

Primary goal: Study MB Low-E excesses

Do a $\nu_\mu \rightarrow \nu_e$ + "n-tag" oscillations search

Excess is CCQE → No excess in MB+
Excess due to NC processes → Excess persists

Complimentary to MicroBooNE

Other studies: Δs …

Mexican participation in MB

ICN-UNAM (A.A.) has maintained participation in the experiment during its final phases.

Current responsibilities:

- Data reprocessing
- ν/POT stability analysis
- Operations

New interest given the opportunity to search for certain DM candidates, and possibly **MiniBooNE+**.

New chances to become involved in new analyses

$\rightarrow$ opportunities for new students and collaborators.

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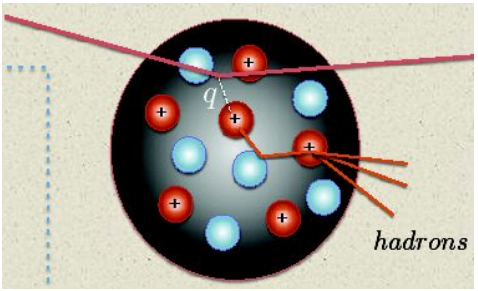
MINERvA experiment (FNAL e938)

(**M**ain **IN**jector **E**xpe**R**iment for **ν-A**)

- Uses the ***NuMI*** neutrino beam at Fermilab.
- **Goals:** Study ν ($\overline{\nu}$) – Nucleon interactions, in a variety of targets (H2O, Pb, He, C, Fe, plastic, etc.)
  - Useful for neutrino oscillation experiments
  - Effect of dynamics of strong interactions dynamics on neutrino-nucleon interactions.



- Data from 2010 - 2012 (3 GeV) → analysis in progress.
- Data taking 2013 - 2016 (6 GeV) ongoing.

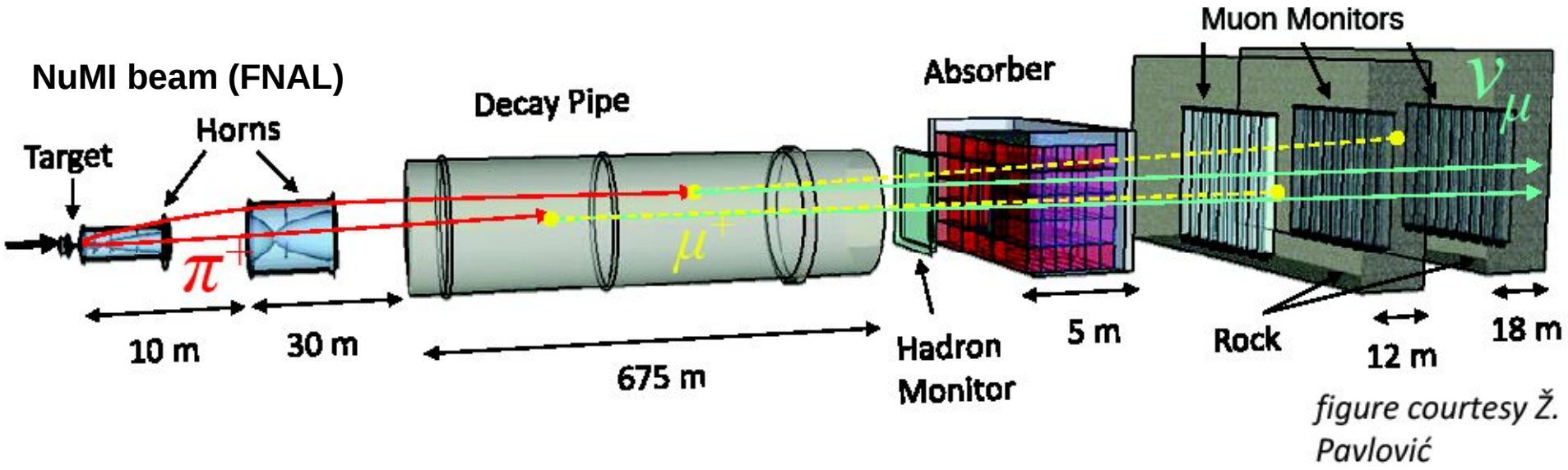


figure courtesy Ž. Pavlović

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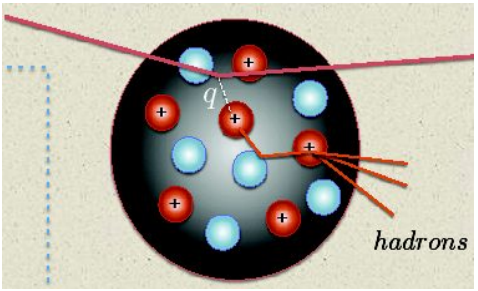

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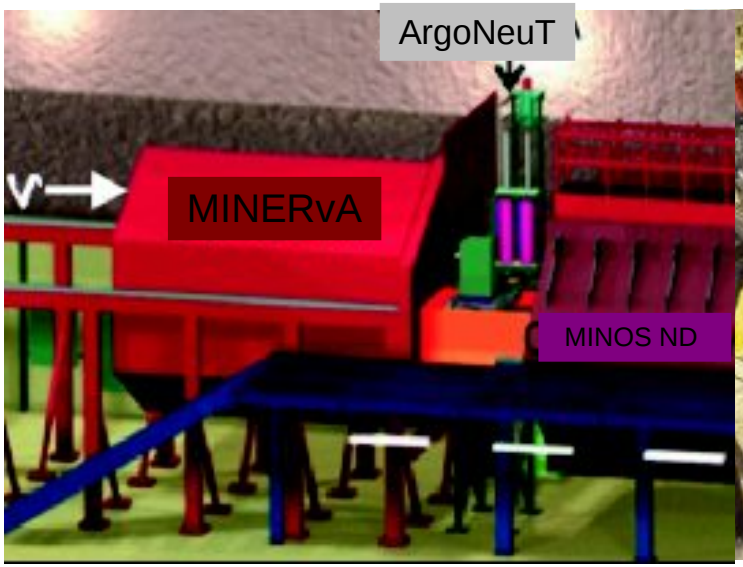

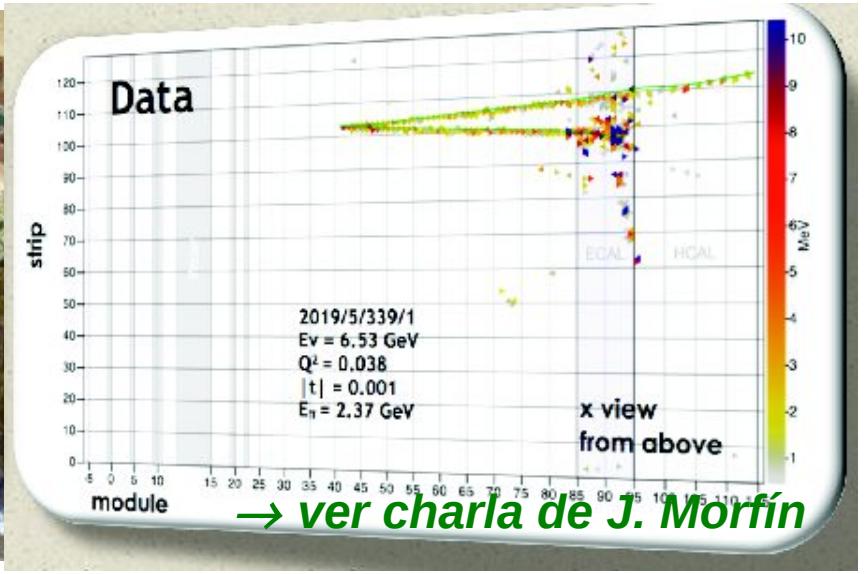

→ *ver charla de J. Morfín*

Mexican participation in MINERvA

Universidad de Guanajuato,
Experimental High Energy Physics group
Led by Dr. Julián Félix
Official member institution in MINERvA (*ca.* May 2007)

High Energy Physics Lab: created in 2006; developed with support from Univ. Gto, FERMILAB, CONCYTEG, CONACYT and the MINERvA collaboration.

Graduates: - 13 Lic.., 6 MSc, 1 PhD (Physics)
Also: - 25 Social Service / Professional

Analysis led by Mexican group:

Coherent CCπ+ production at ~3 GeV

Currently: 1 Postdoc, 4 PhD, 8 Lic (Phys & Comp. Sc), 2 Social Serv.

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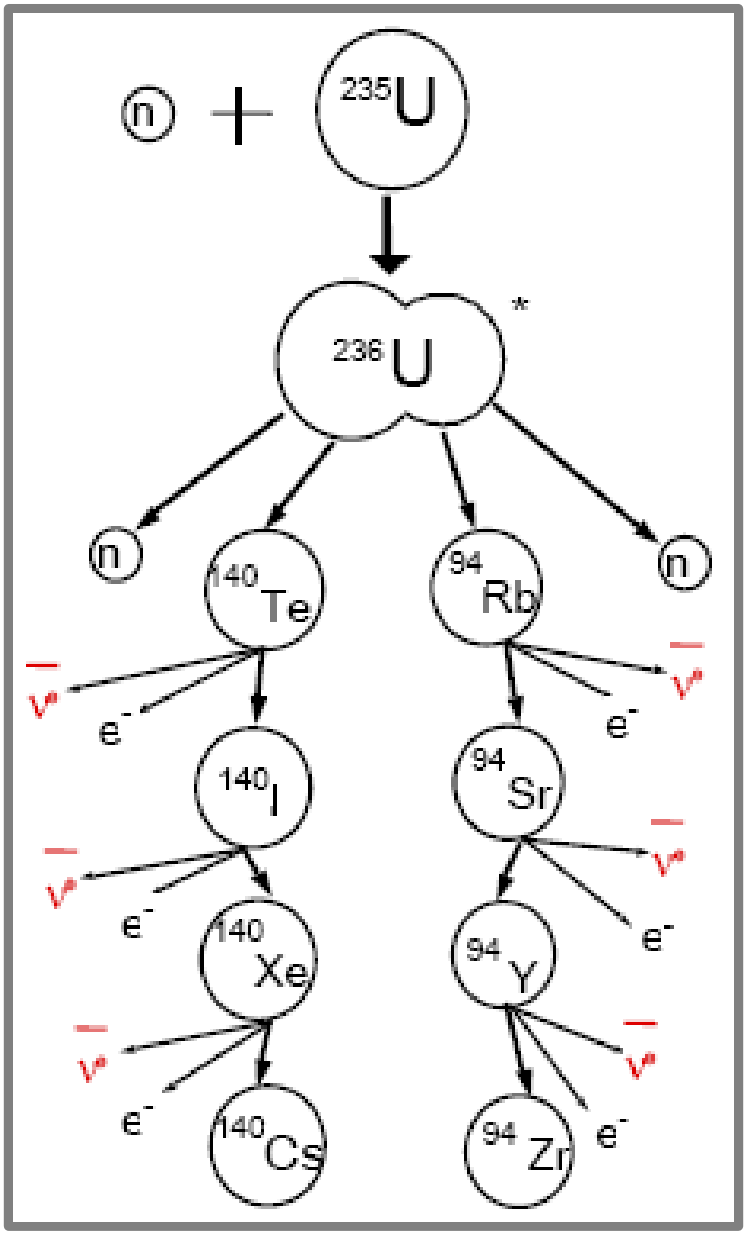
Nuclear reactors as antineutrino sources

β^- decay: $^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^- + \bar{\nu}_e$

	^{235}U	^{239}Pu	^{238}U	^{241}Pu
$E_{Fisión}$(MeV)	202	210	205	212
$\langle E_\nu \rangle$ (MeV)	1.46	1.32	1.56	1.44
$\langle N_\nu \rangle$ (E_ν>1.8 MeV)	5.58 (1.92)	5.09 (1.45)	6.69 (2.38)	5.89 (1.83)

Typically: ~ **2×10^{20} $\bar{\nu}_e$ *sec/GWatt***

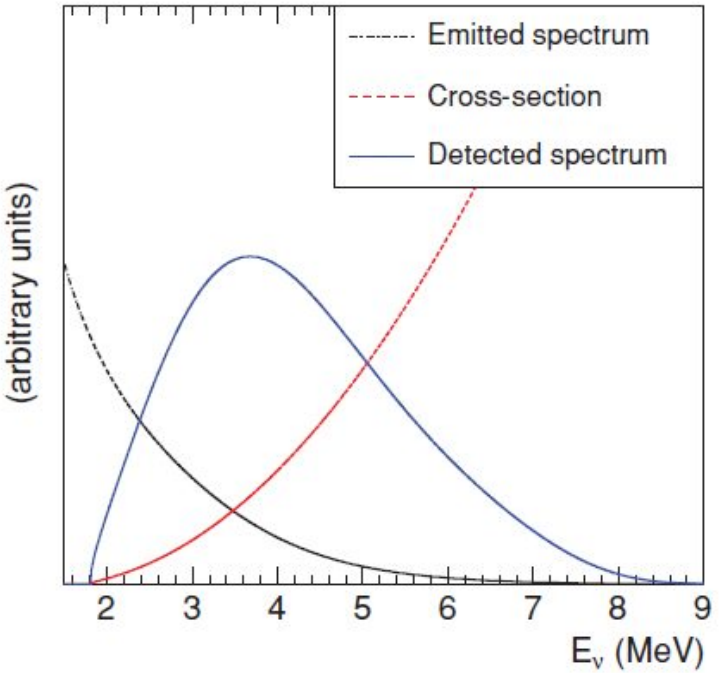
Flux determined by:
1. reactor thermal power
2. Fusion rates of U^{235}, U^{238}, Pu^{239}, Pu^{241}



Detecting reactor antineutrinos

Detection by ***inverse β decay***:

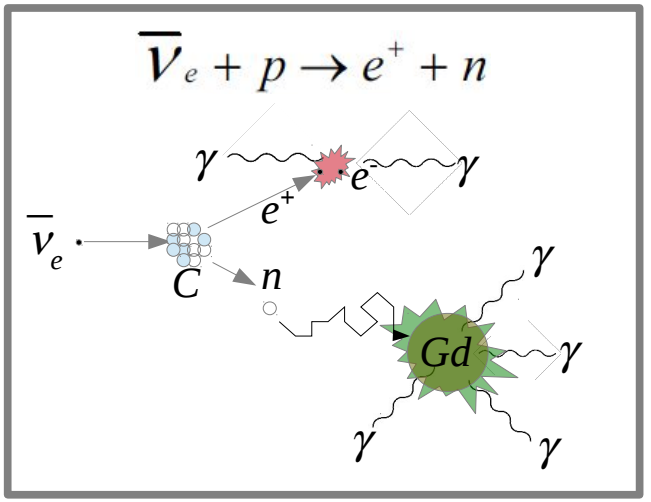
- Reaction threshold: E_ν>1.8 MeV
- Cross section ($\propto E_\nu^2$): $\langle\sigma\rangle \sim 10^{-43}$ cm^2



Signal e^+: Cherenkov+γ's (annihilation)

Signal *n*: γ's from n capture in Gd (~30 μs, ~8MeV)

Delayed coincidence of the e^+ and n signals → $\bar{\nu}_e$ interaction.



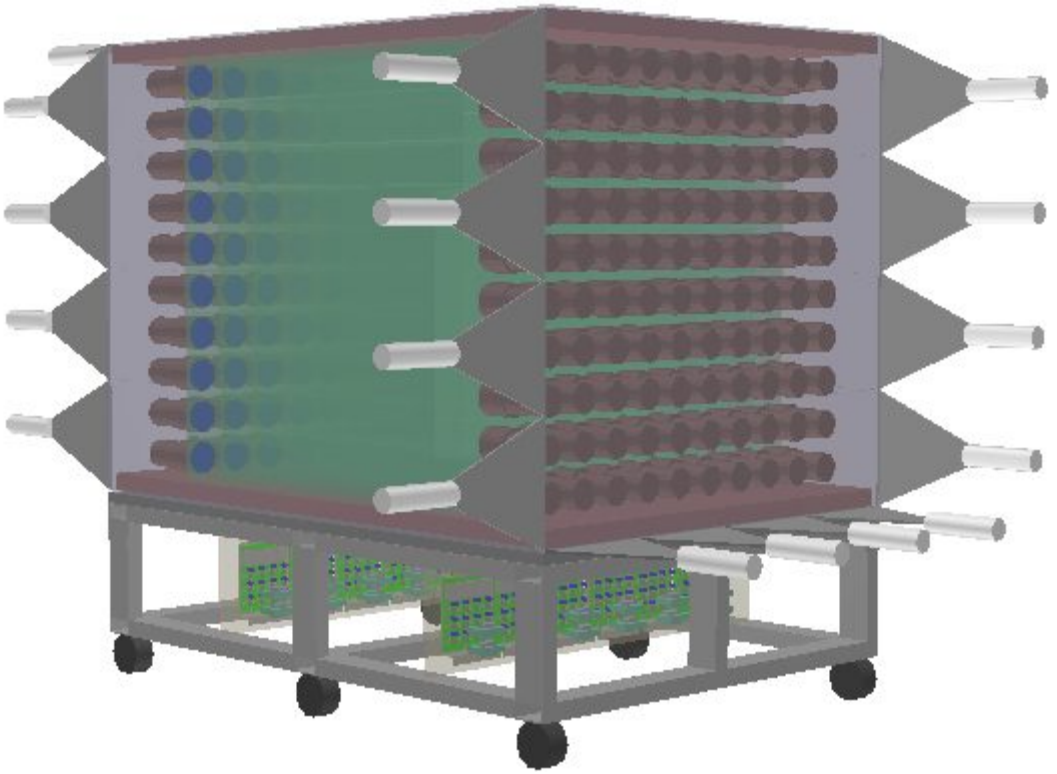
Reactor monitoring with $\bar{\nu}$'s

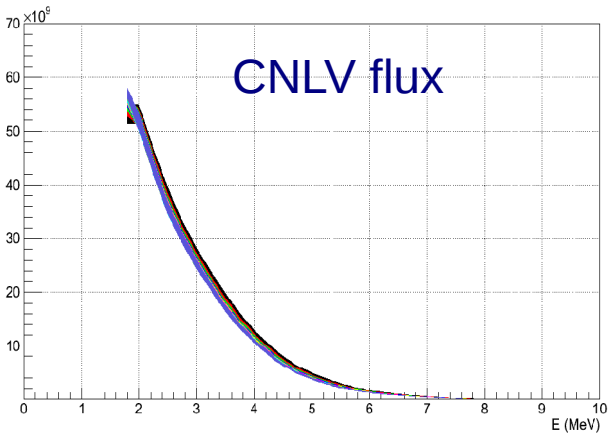
Working idea Show On/Off effect:

- 1 Ton ($1m^3$) of plastic scintillator with Gd-doped coating.

- Instrumentation: PMT's or APDs + extruded fibers

- Distance to cores ~ 100 m.





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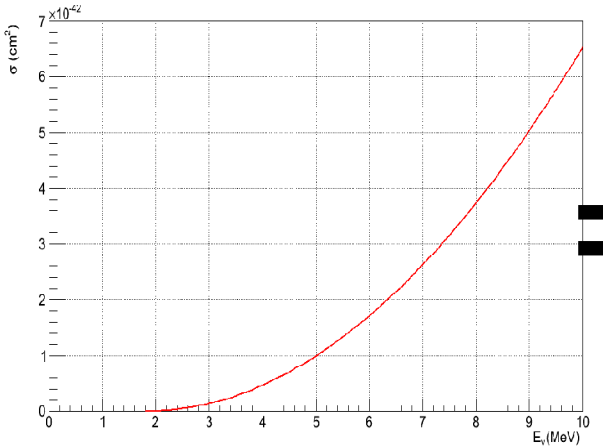

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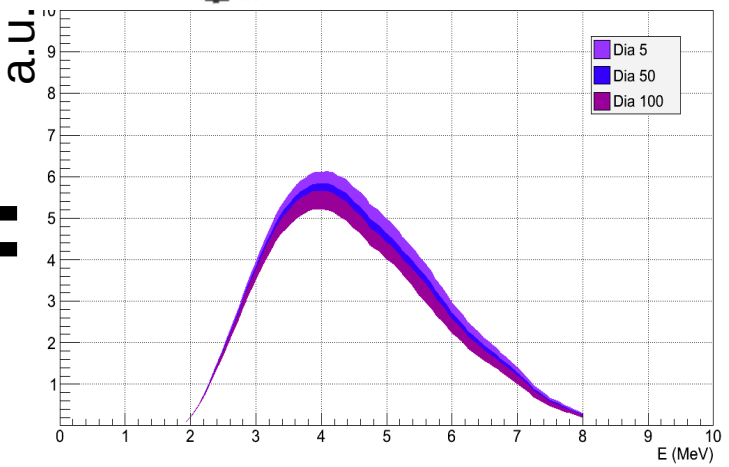

Exp: 300-700 ev/day @100 m

Reactor monitoring with $\bar{\nu}$'s

Scientists from several institutions interested in the development of a detector reactor neutrino monitoring (possibly at CNLV).

ICN-UNAM: Precise determination of the flux from a BWR-5 (CNLV reactors).

UAS: Synthesis of large Gd-doped plastic scintillators

UMSNH: Fast electronics for DAQ.

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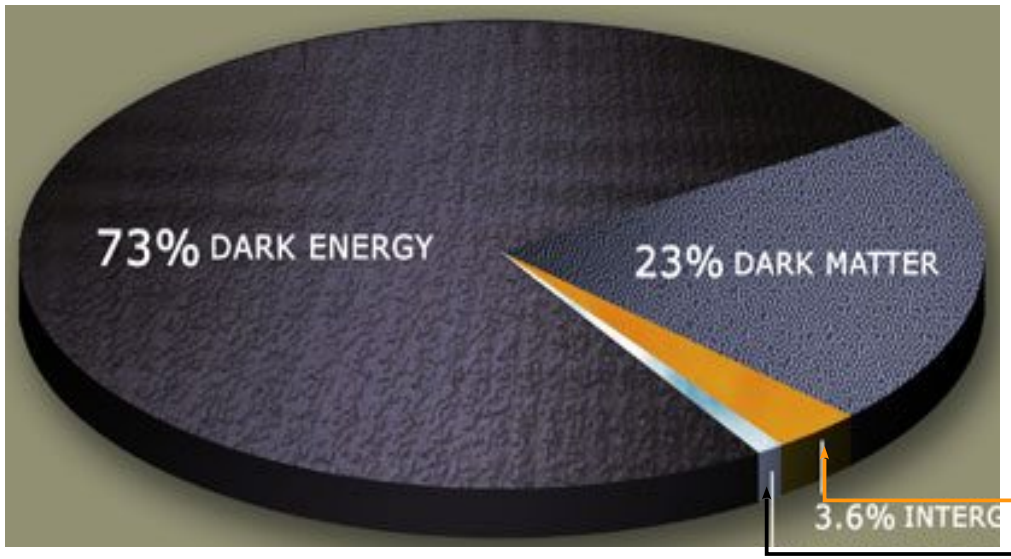
Dark Matter

Astrophysical and Cosmological observations

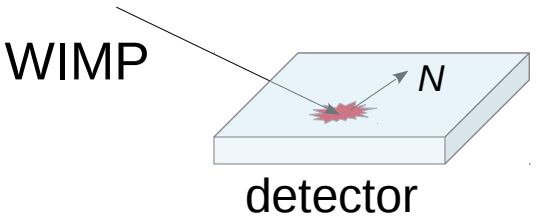
→ Evidence in favor of the existence of Dark Matter

ΛCDM Model of the Universe : Ω_Λ(~73%) + **Ω_{cdm}(~23%)** + Ω_b(~4%)



Best Candidate: **WIMP**'s
(**W**eakly **I**nteracting **M**assive **P**articles)
Mass: 1–1000 GeV/c^2,
Cross section, σ: 10^{-43} – 10^{-38} cm^2

Direct DM searches:



Count the rate of nuclear recoils above an energy threshold, and look for an ***excess*** above the expected background

massive and ultra-sensible detectors in underground laboratories.

(E_{th} ~0.01-100 keV)

Reduce cosmic ray flux

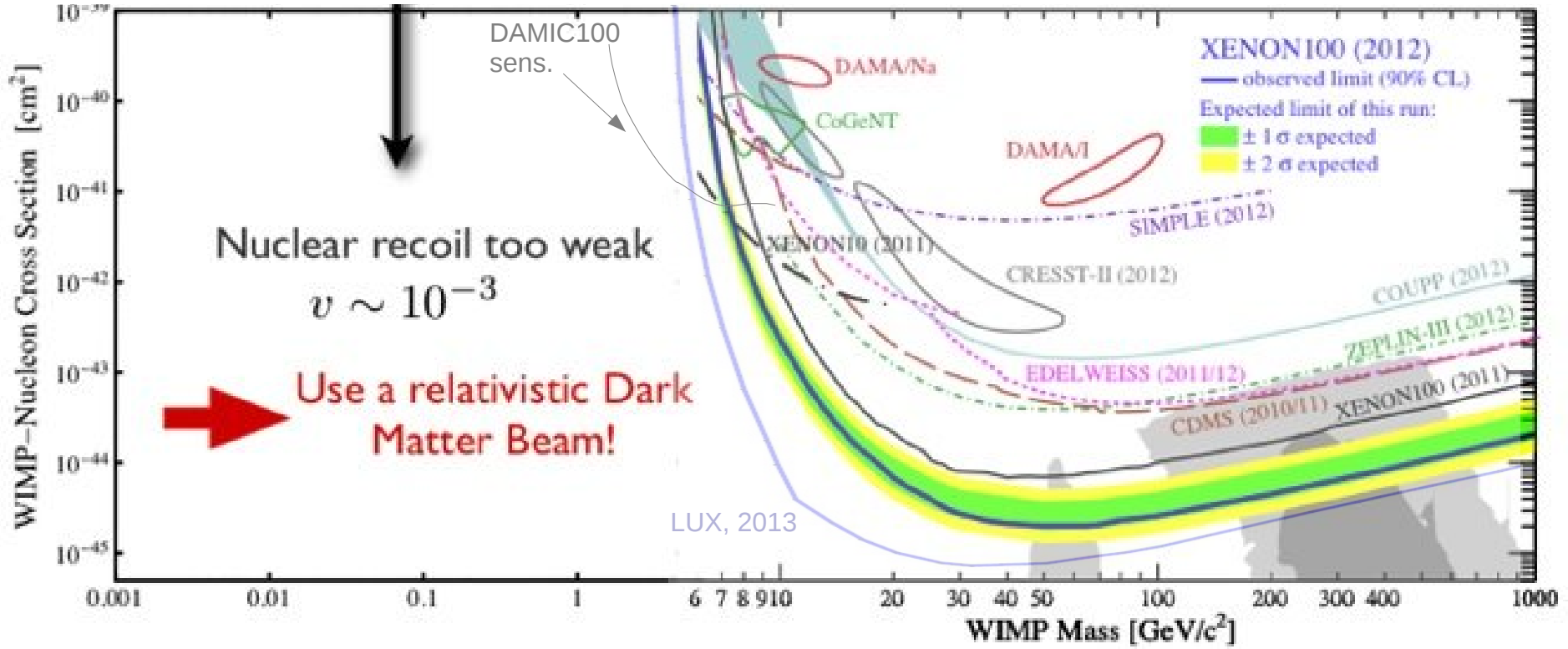
MiniBooNE: Light Dark Matter Search

- 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. deNiveville, D. McKeen, A. Ritz, Phys.Rev. D86, 035022 (2012)

← Our theory collaborators

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



Light Dark Matter

- A minimal extension to the Standard Model:

Secluded U(1)' sector with weak admixture to photons (SB<1GeV)

Dark sector $\longleftarrow \kappa \longrightarrow$ Standard Model

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

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

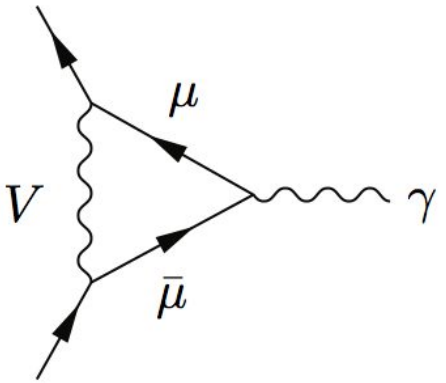
4 parameters: $m_\chi,\ m_V,\ \kappa,\ \alpha'$

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 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)



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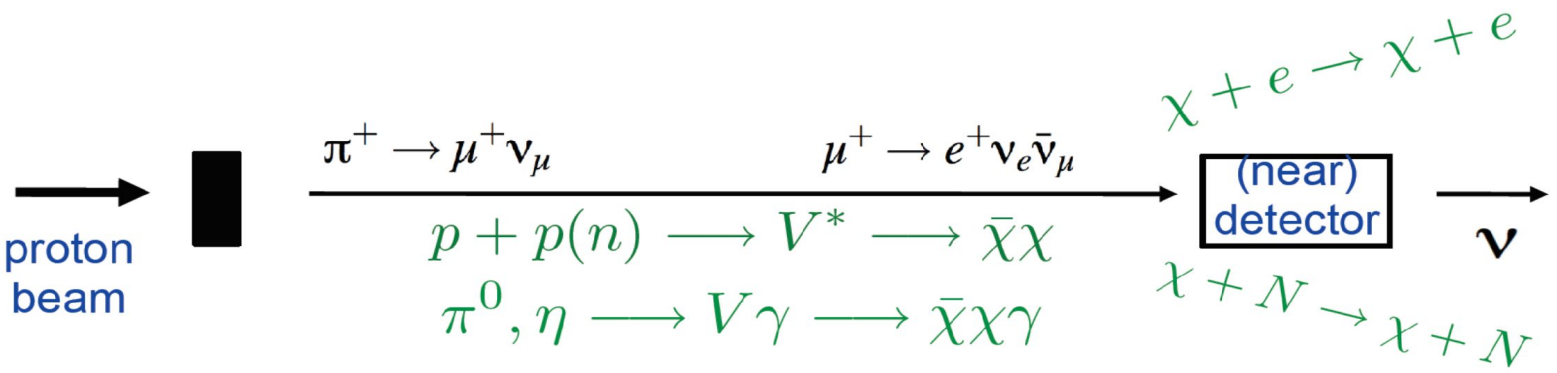
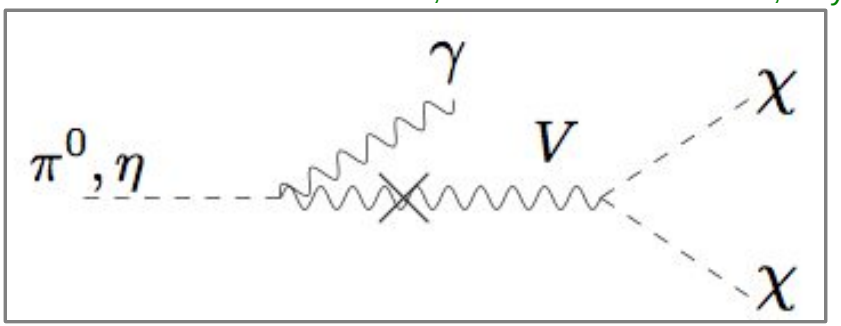
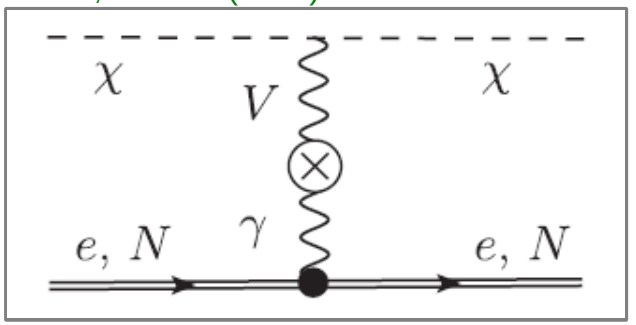


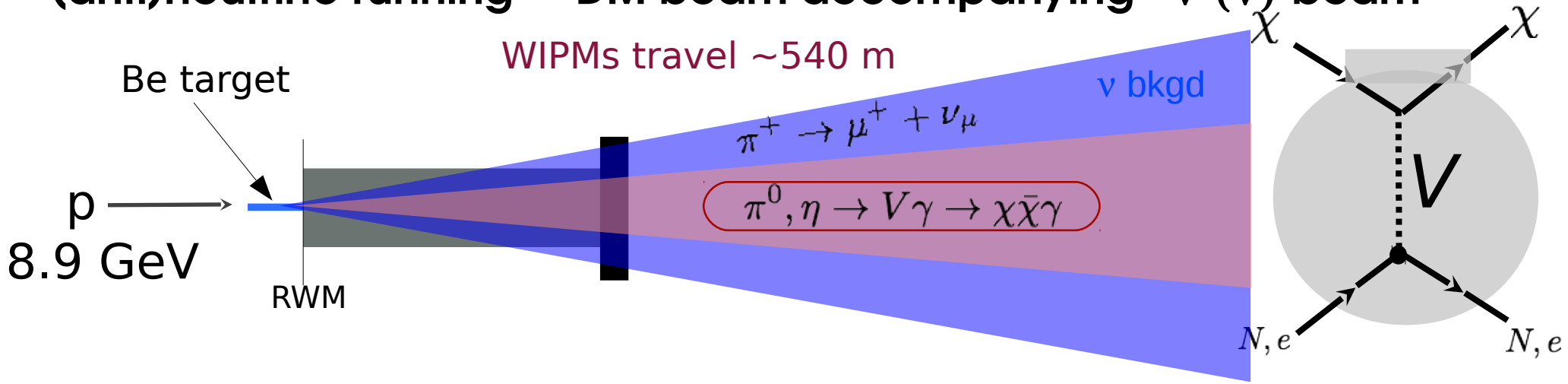
P. deNiverville, D. McKeen and A. Ritz, Phys. Rev. D 86, 035022 (2012)



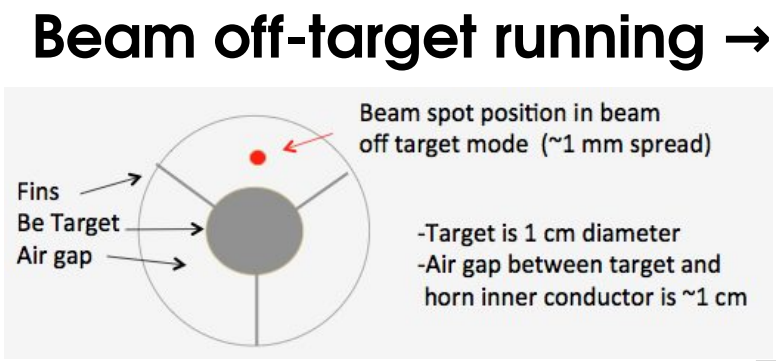


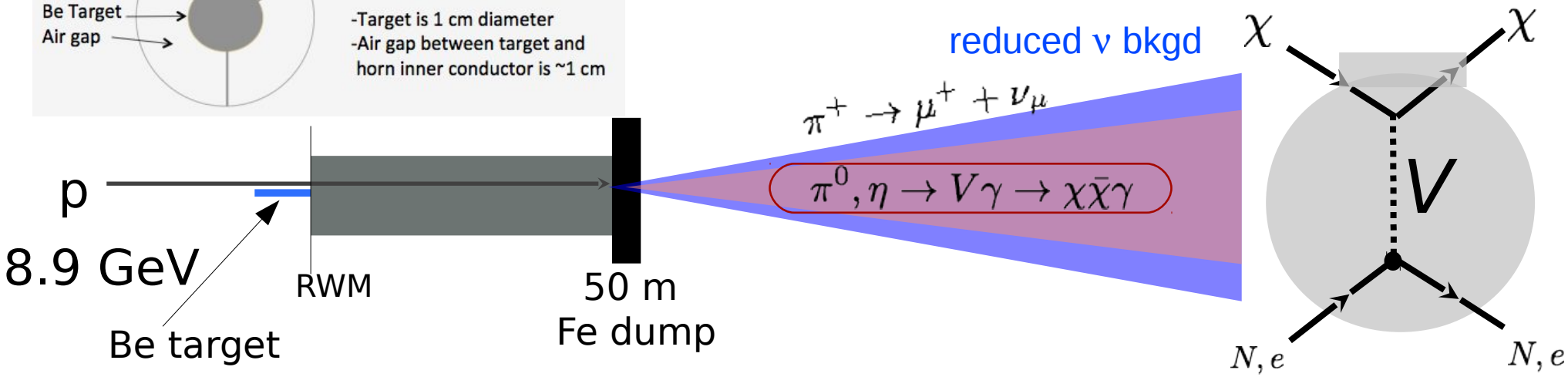
Dark Matter production/detection

- **(anti)neutrino running → DM beam accompanying $\bar{\nu}$ (ν) beam**



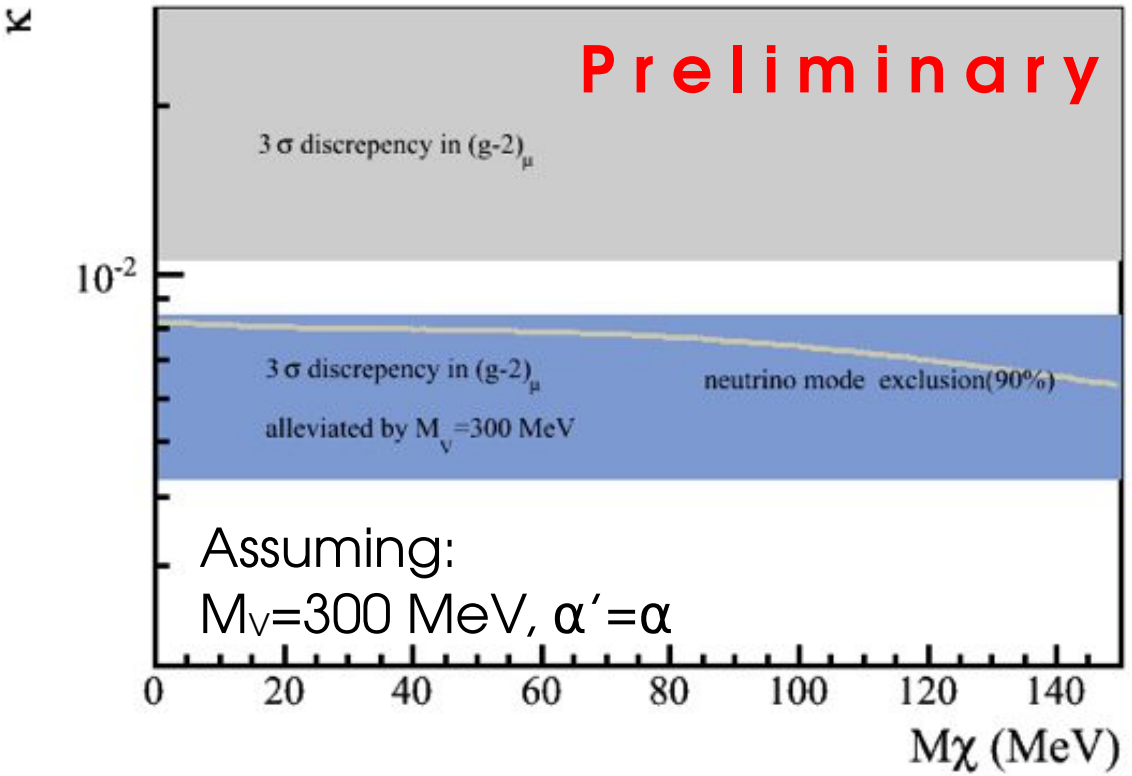
- **Beam off-target running → neutrino background reduction by factor~70!**



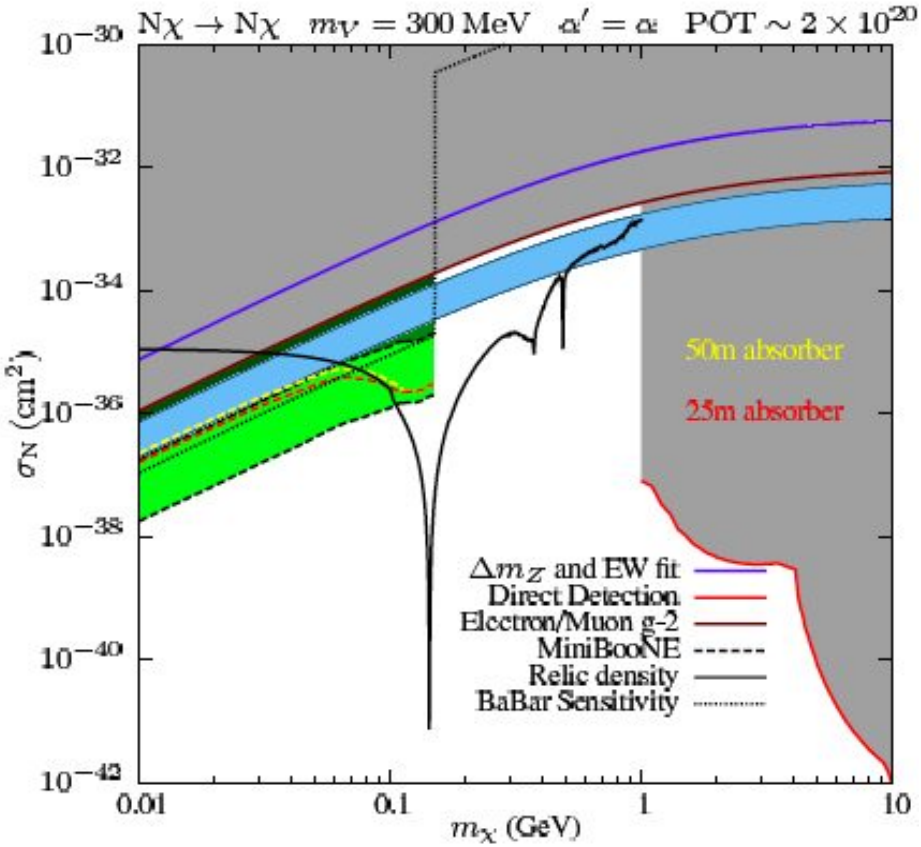


MiniBooNE: WIMP search

Neutrino mode Result:
νNCE analysis 6.4E20 POT



Beam off target expectation



Plot 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.

Mexican participation in MB-DM

Current Responsibilities:

- Data reprocessing
- Stability analysis
- Operations

Future:

- Depends on PAC response to proposals
- Might only last for one short run, before MicroBooNE.
- Might lead to dedicated intensity frontier experiments where we could collaborate.

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Dark Matter In CCD's

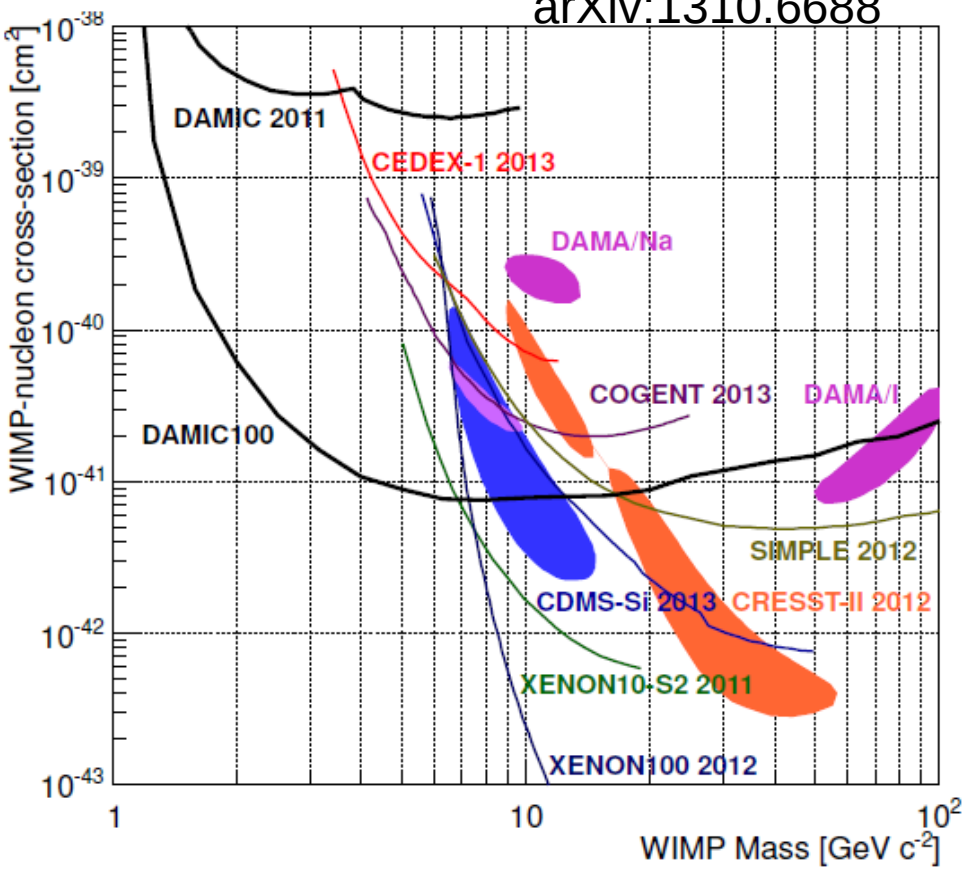
DAMIC: (SNOLAB, Sudbury, Canada)
- Search for light WIMPs (M~1–50 GeV/c^2)
- CCD technology (Si, E_{th}~40 eVee)
- Operating @SNOLAB since Dec 2012

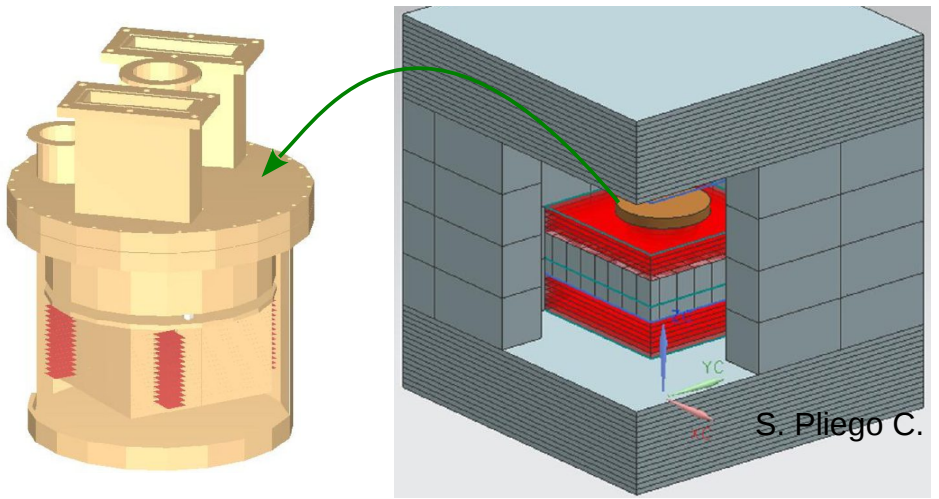
DAMIC-100: (100g of Si en CCDs)
- Will explore some recent "*Hints*" of DM sig's.
- UNAM actively involved (3 res + 5 students).

➔ ***See Talk by Gustavo Cancelo***

DAMIC-400: (400 g of Si)
- UNAM group working on a design

Place similar detectors at different latitudes
➔ DAMIC-South





Mexican participation in DAMIC

(ICN-UNAM, IIngen-UNAM)

- Contribution ($$) to the DAMIC-100 upgrade.
- Thermal modeling of the detector (*see F. Trillaud's Talk*)
- R&D on the Implementation of the CCD readout with a commercial system (Leach Inc.).
- Design and simulation of DAMIC-400 upgrade.
- Sensitivity studies of DAMIC-400.
- Will participate in DAMIC-100 operations starting on 2014-2015.

Summary

- Growing participation in neutrino and Dark Matter search experiments in Mexico.
- Working on strengthening our bonds with co-nationals working in similar projects abroad.
- DAMIC experiment is our first participation (institutional level) in an experiment in an Underground Lab.

Thank you!