Light Mass WIMP Searches with a Neutrino Experiment:

The MiniBooNE Search

P-25 Seminar

Feb 26, 2013

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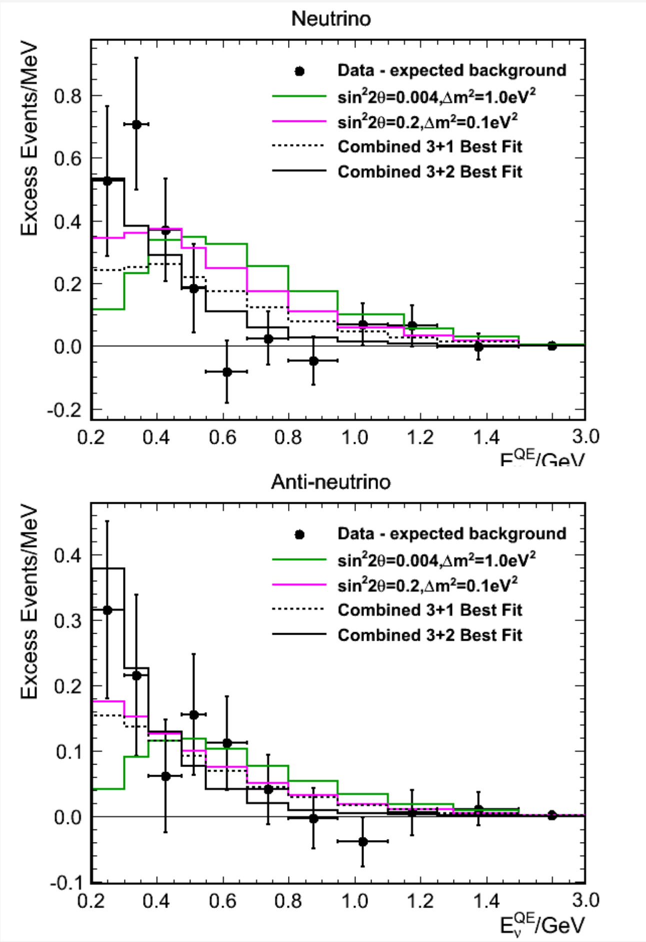
Outline

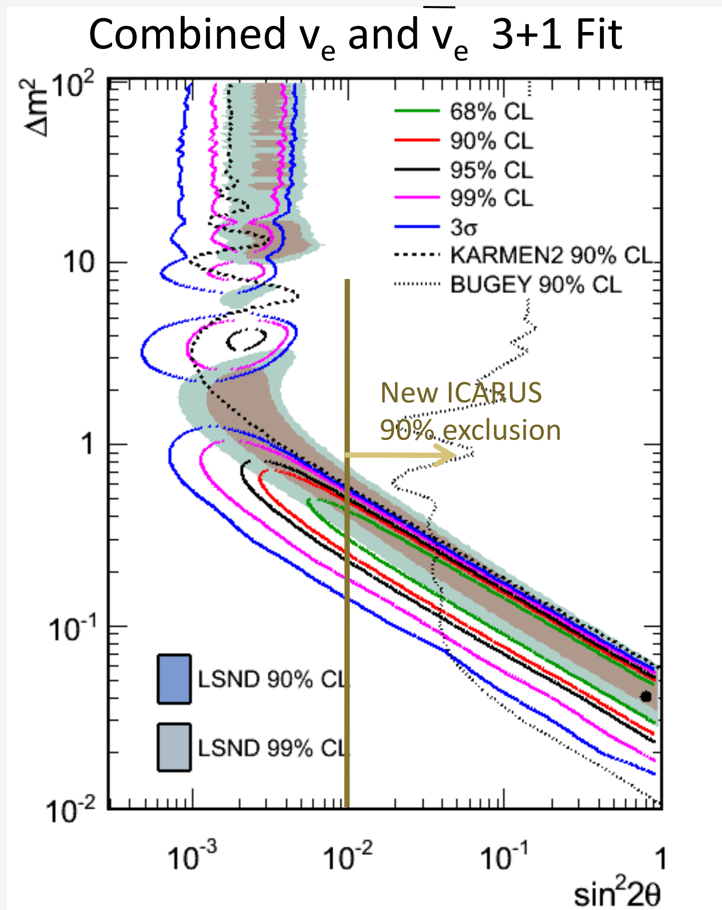
- Summary of 10 years of MiniBooNE neutrino/antineutrino running.
- The case for light mass WIMPs (<1 GeV) and how to produce them with protons beams.
- MiniBooNE enhanced WIMP sensitivity with beam off target running.
- MiniBooNE WIMP detection methods, sensitivities and limits.
- Future possibilities with MiniBooNE, new experiments with the Main Injector.
- Conclusions.

Ten Years of Successful MiniBooNE Running and Results!

- Neutrino mode: 6.5E20 POT
- Antineutrino mode: 11.3E20 POT
- 10 oscillation papers
- 12 cross section and flux papers
- 1 detector and 1 supernova search paper
- 17 PhD thesis
- The experiment is well understood!

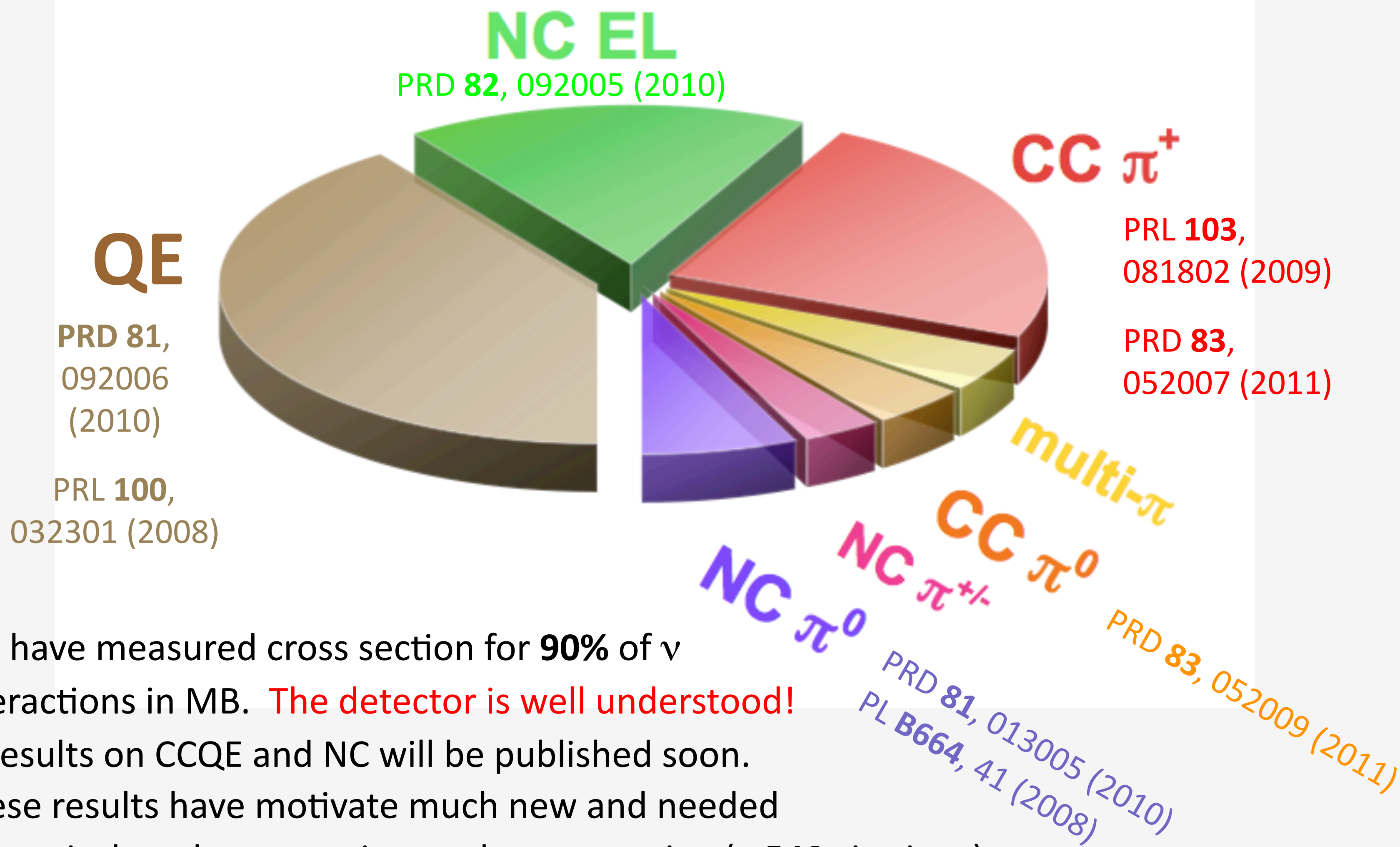
Ten Years of MiniBooNE Running: Oscillation Results





- Combined ν_e and $\bar{\nu}_e$ Event Excess from 200-1250 MeV = 240.3+-34.5+-52.6 (3.8σ)
- We fit for oscillations (3+1 – two neutrino model), and find consistency with LSND.
- However, with one detector, this is not proof of oscillations. Could the excess, or some part of it be caused by a new background, or other physics?

Ten Years of MiniBooNE Running: Cross Section Results



- We have measured cross section for **90%** of ν interactions in MB. The detector is well understood!
- $\overline{\nu}$ results on CCQE and NC will be published soon.
- These results have motivate much new and needed theoretical work on neutrino nucleus scattering (> 540 citations)

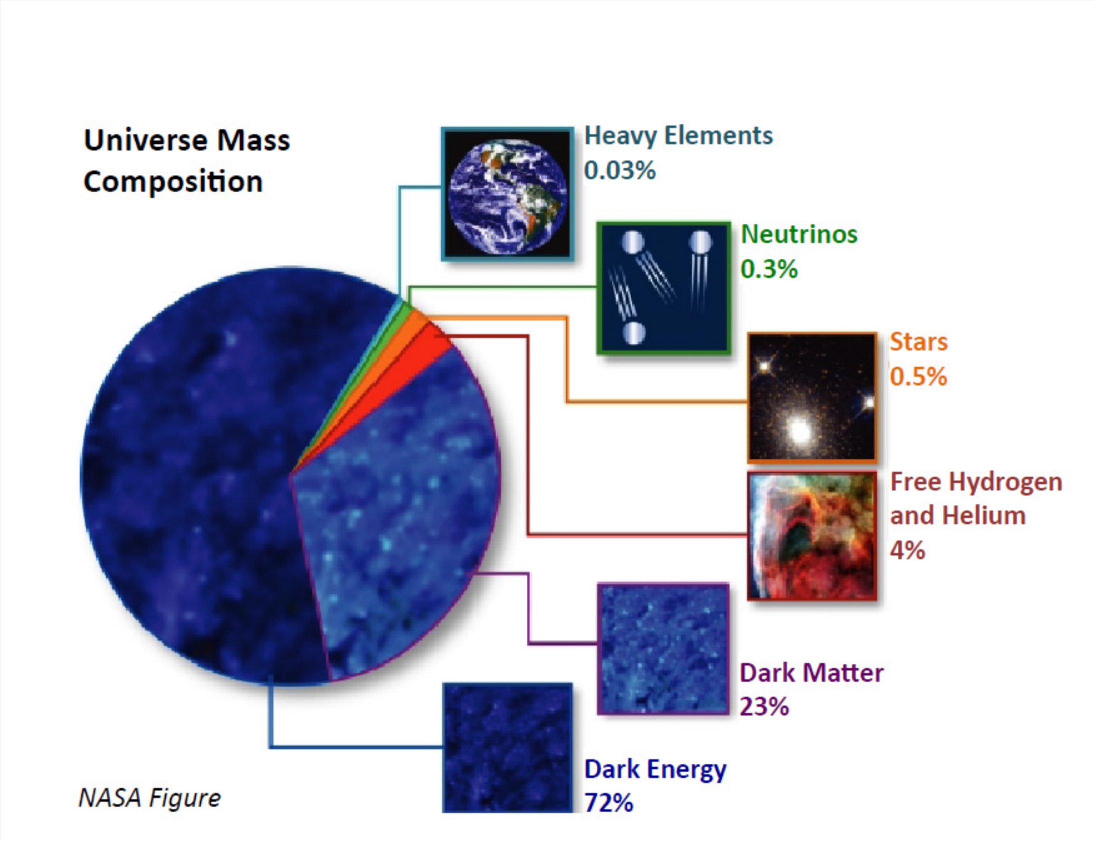
Is Further Neutrino/AntiNeutrino Running with no Changes Worthwhile?

- Neutrino Running: NO -- we are systematic limited, more running would not significantly improve the results.
- Antineutrino Running: Maybe – we are still statistics limited, but would take many years to double the data.
- We need a significant systematic change to add new information to the question of oscillations.
  - Submitted a LOI to add scintillator to the detector and run concurrently with MicroBooNE.
  - Recent beam timing analysis hints that we can separate electrons from gamma-rays. More running in neutrino mode with improved timing might be worthwhile.
- Something completely different…

A New Idea: WIMP Searches at MiniBooNE

- Can WIMP Dark Matter be light (sub-GeV)?
- Yes! What are the constraints on such a scenario? What does a model look like?
- Consequences of the model for other observations, e.g. muon g-2.
- If WIMPs are light, how can MiniBooNE produce and detect them.
  - Need lots of relativistic protons and a large detector!

The Search for Dark Matter is Well Motivated



- From the NASA Web site: By fitting a theoretical model of the composition of the Universe to the combined set of cosmological observations, scientists have come up with the composition that we described above, ~70% dark energy, ~25% dark matter, ~5% normal matter. What is dark matter?

What is Dark Matter

- The chief property of dark matter is that it is "dark", i.e. that it emits no light.
  - Not visible, not x-ray, not infrared. In addition, dark matter must interact with visible matter gravitationally, i.e. galactic rotation curves, etc.
- The two main categories of objects considered as possibilities for dark matter include MACHOs, and WIMPs.
  - MACHOs: Massive Astrophysical Compact Halo Objects such as brown dwarfs, black holes, etc.
  - WIMP (Weakly Interacting Massive Particles) candidates include active/sterile neutrinos, neutralinos, axions, dark photons, etc.

Properties of WIMPs

- However, the evolution of structure in the universe indicates that the dark matter must not be fast moving, since fast moving particles prevent the clumping of matter in the universe. So while neutrinos may make up part of the dark matter, they are not a major component. Particles such as the axion and neutralino appear to have the appropriate properties to be cold dark matter.
- Neutralino: predicted by Supersymmetry, usually with masses > 10 GeV. Can be produced thermally in the early Universe and leave the right relic abundance to account for the dark matter.
- Axion: Invoked to solve the "strong CP problem", i.e. lack of QCD CP violation. Axion masses are usually considered small < 1 MeV.

Relic Density Arguments

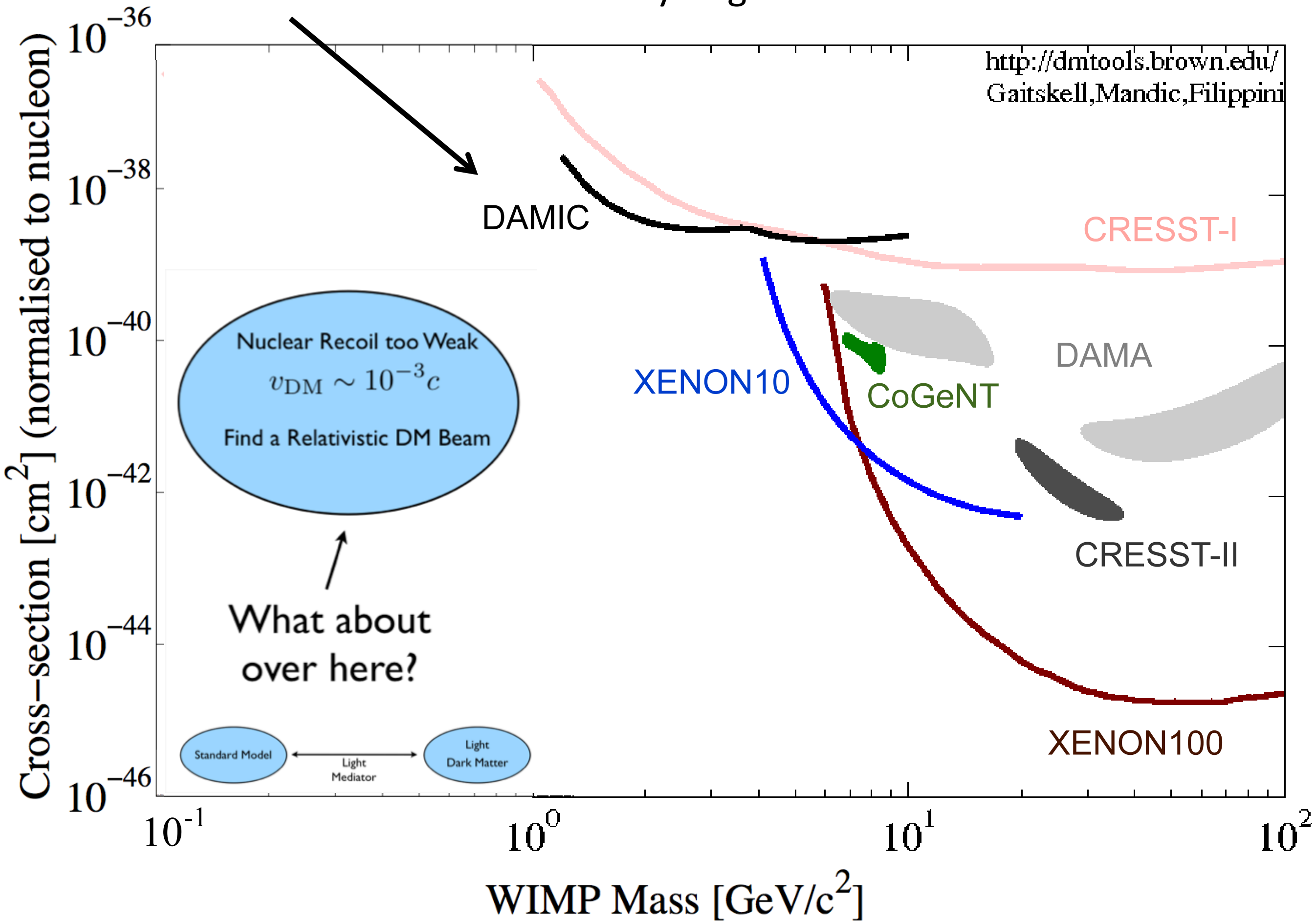
- In the early Universe, the high density of WIMPS would self annihilate. Evolution of the Boltzmann equation gives:

$$\Omega_{Wimp} \approx \frac{10^{-26}\text{cm}^3\text{s}^{-1}}{\langle \sigma v \rangle}$$: $\langle \sigma v \rangle \sim (M_{Wimp} G_f)^2$ for $M_{Wimp} << M_W$

- <σv> is the thermally averaged cross section and is roughly the weak scale for Ω = 1 – the "WIMP miracle"
- Lee Weinberg limit (SM mediators W, Z) implies $M_{wimp} >> 2\text{GeV}$
  - The lower the mass of WIMPs is, the lower the annihilation cross section*. This means that low mass WIMPs freeze out (i.e. stop interacting) much earlier and thus at a higher temperature, than higher mass WIMPs. This leads to a higher relic WIMP density. If the mass is lower than ~2 GeV the WIMP relic density would overclose the universe.*
- This is one reason why WIMP searches below a few GeV has not been vigorously pursued.
- However, to date, Supersymmetry and WIMPs above ~GeV have not been conclusively observed. Maybe we should start looking elsewhere….

World Data on Low Mass Spin Independent WIMP Scattering

Traditional underground direct detection experiments run out of sensitivity below ~1 GeV due to the low velocity of galactic halo WIMPs

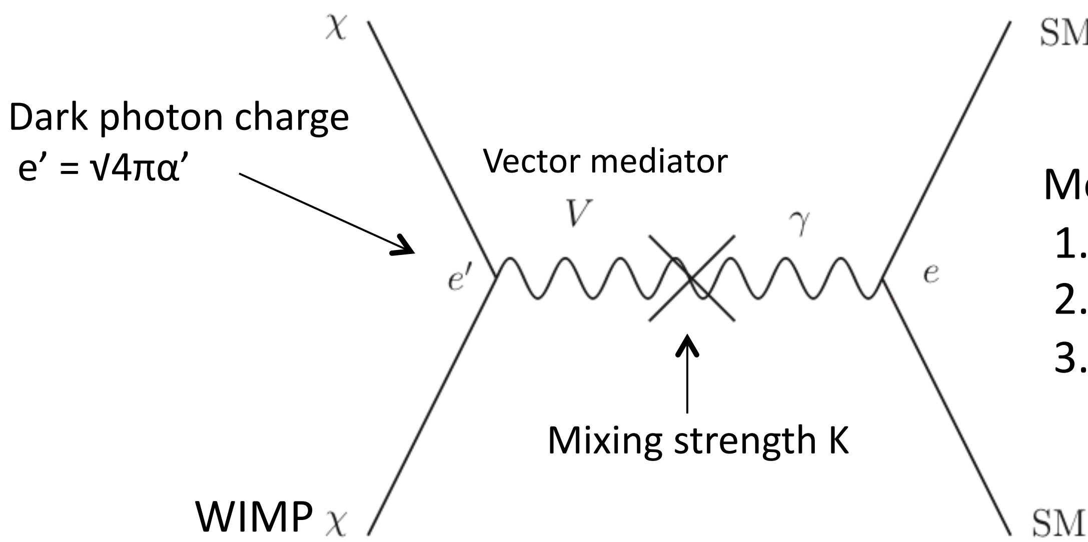


However, for low mass WIMPs you need a new model to produce the right relic density!

Minimal U(1) Dark Force Vector Portal Model

Required for Low Mass WIMPs to achieve correct thermal relic abundance

$$\mathcal{L}_{\rm DM} = V_\mu \left(e\kappa J^\mu_{\rm em} + e' J^\mu_\chi \right) + \mathcal{L}_{\rm kin}(V, \chi) + \cdots$$



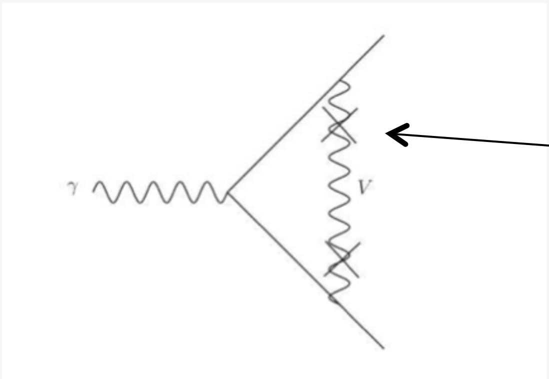
Model assumptions:

1. e = e' (perturbative regime)
2. K is small
3. $M_v > 2M_x$

Assuming thermal relic, if you know $m_\chi,\ m_V,\ \kappa,\ e'$ you know the present DM density

Model Consequences for Muon g-2

- Light kinetically mixed vector V that serves as a mediator in this model also contributes to the anomalous magnetic moment of SM fermions.
- This can explain the muon g-2 discrepancy.



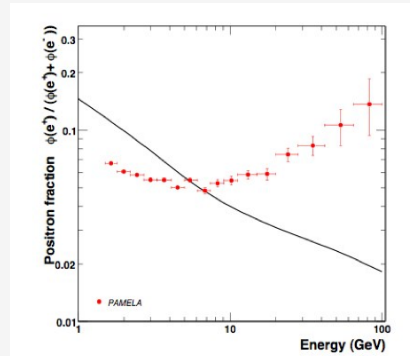
The crosses represent the kinetic mixing κ of the vector V with the photon

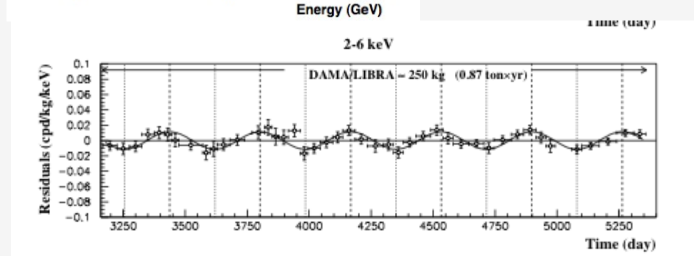
Experimental Consequences

- Cosmology
  - -CMB: OK given p-wave annihilation — Padmanabhan & Finkbeiner '05
  - -BBN: OK for $m_\chi \gtrsim 1 \text{ MeV}$ — Jedamzik & Pospelov '09
  - -Star Cooling: OK for $m_V \gtrsim 1 - 10 \text{ MeV}$
- Particle Physics
  - -Monophotons/Monojets $pp/p\bar{p} \to \chi\chi + (\gamma,\, j)$ — Shoemaker & Vecchi '11, Fox *et al.*
  - -Dark Force searches $e^+e^- \to \gamma V \to \gamma \ell^+ \ell^-$ — Bjorken *et al.* '09, Batell *et al.* '09, MAMI, APEX, BABAR
  - -Rare Meson Decays $K^\pm \to \pi^\pm V \to \pi^\pm + \text{inv.},\ J/\psi \to V^* \to \text{inv.}$ — E949, CLEO
  - -MiniBooNE

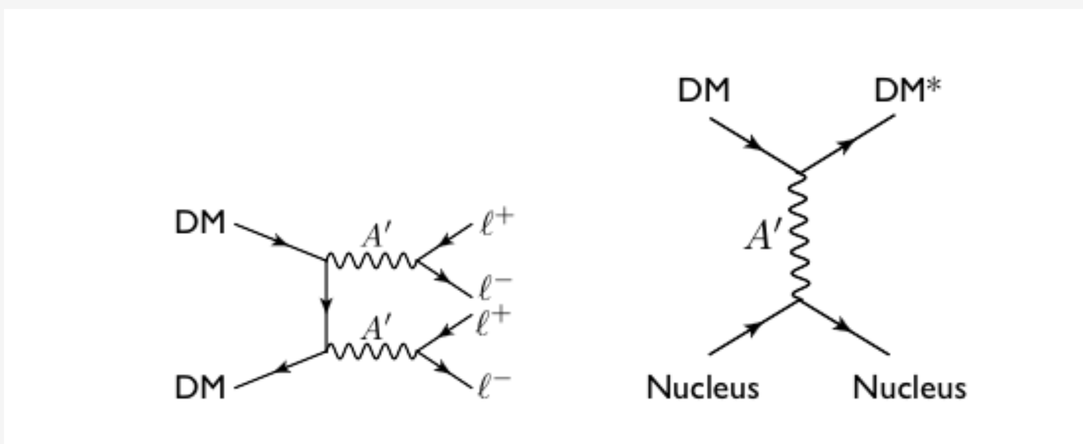
PAMELA and DAMA Signals: A Case for light Dark Matter mediated by new Vector Boson Force

- PAMELA: cosmic-ray electron and positron excess from WIMP annihilation. Will AMS say more??
- DAMA: Time varying WIMP scattering due to inelastic scatter that modulates with Earths velocity around the Sun





PAMELA DAMA

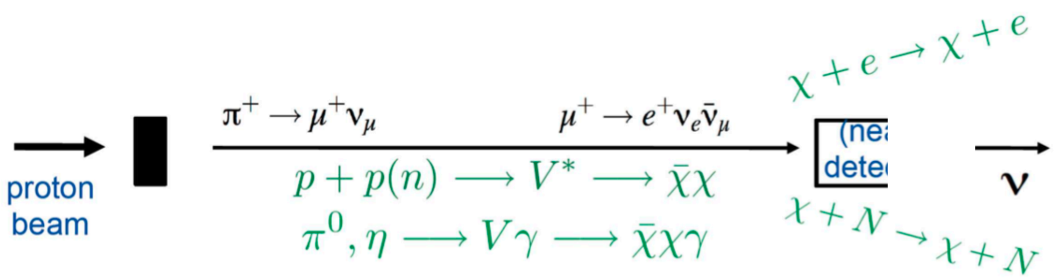


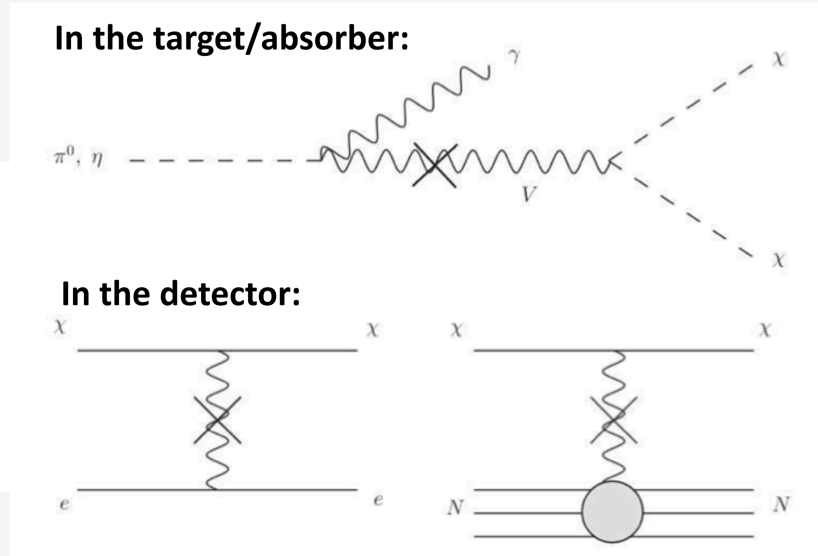
From Maxim Pospelov (Perimeter Institute/U. of Victoria)

Why searching for new gauge boson(s) at low and medium energies is important

1. Standard Model is built on SU(3)xSU(2)xU(1) interactions. *Testing for existence of additional gauge groups is needed.*
2. Hints for new sub-GeV gauge bosons might be given to us by *several particle physics anomalies*, most importantly g-2 of the muon.
3. New U(1) groups can serve as mediators of connection between SM and particle dark matter. *Speculative but interesting*.
4. Additional U(1) with kinetic mixing to photons is a very "natural" possibility of new light physics. *It is very simple – even elegant – and extremely predictive.*
5. Significant advances can be achieved using fixed target setups. Only a very small subset of experiments done at low energy can be sensitive to physics beyond SM. Therefore, *it should be done, given a potentially enormous reward in case of a positive result.* 5

Producing a Dark Matter Beam





Electron Elastic scattering

Nucleon Elastic scattering

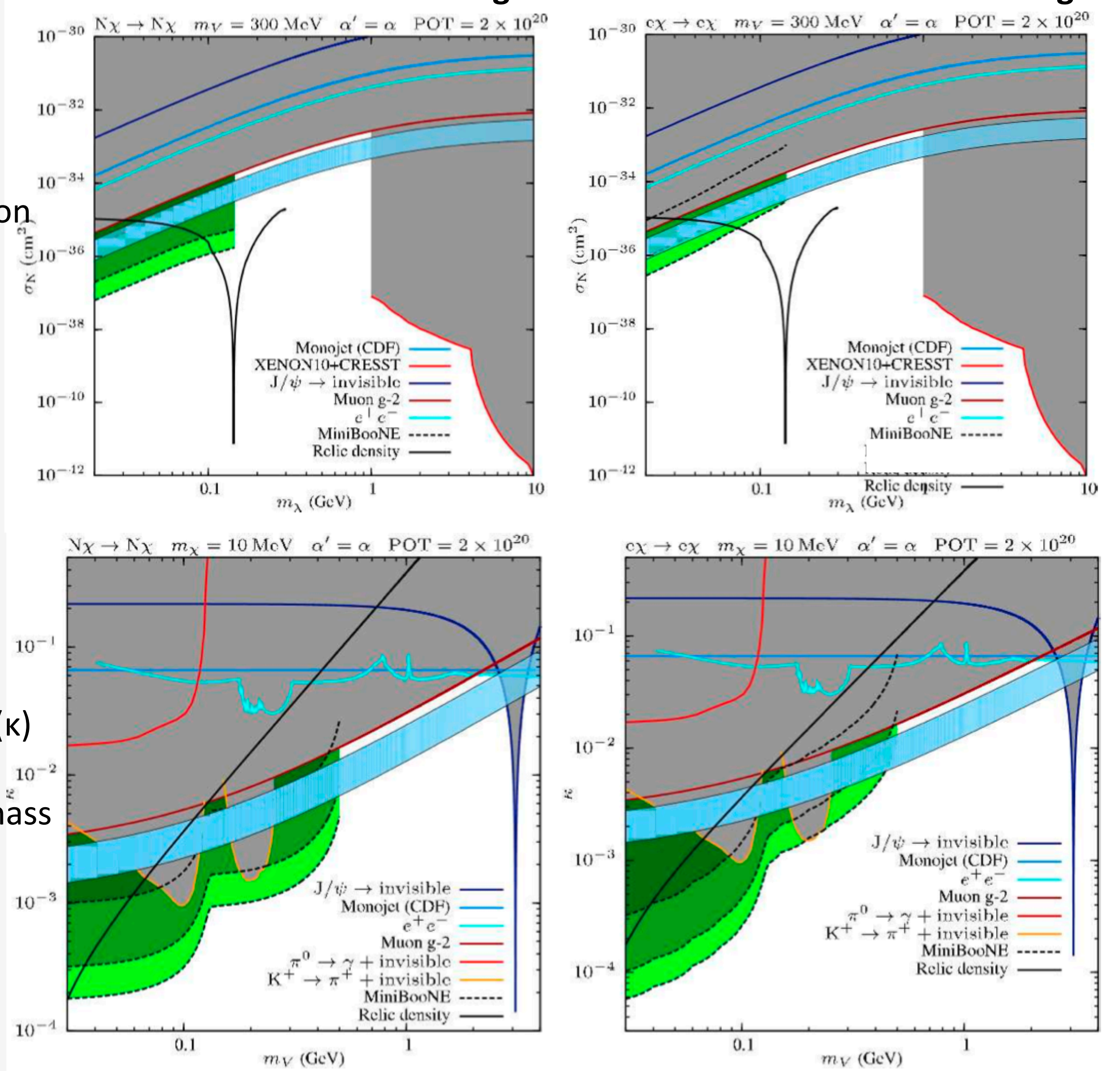
- Monte Carlo Simulation of WIMP Production at MiniBooNE:
  - Use HARP-MiniBooNE Be target Sanford-Wang meson production model.
  - Use MiniBooNE determined acceptance, fiducial, and energy cuts (35% efficiency).
  - Calculate regions of M_χ, M_V, κ, α' parameter space probed for 1, 10, and 1000 events.

MiniBooNE WIMP Sensitivities

WIMP-Nucleon Scattering **WIMP-Electron Scattering**

WIMP cross section
vs
WIMP mass

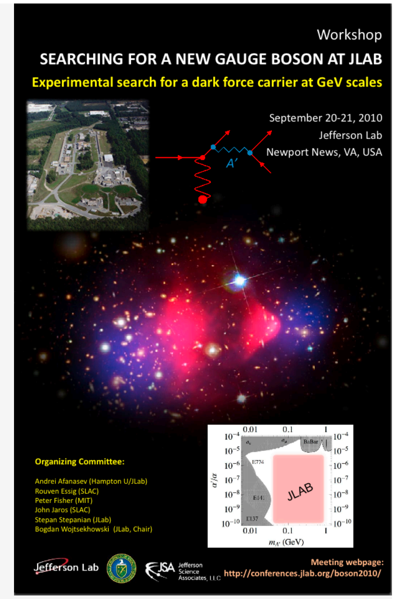
Mixing strength (κ)
vs
Vector mediator mass



- Number of WIMP events detected in MiniBooNE:
  - -Dark Green: >1000
  - -Green: 10-1000
  - -Light Green: 1-10
- What sensitivity can MB actually achieve?
- $2M_x < M_v$ and sensible choice of model parameters M_x, M_v, κ, α′.
- Nucleon cross sections larger than electrons.
- Light blue band is muon g-2 signal.
- Solid black line is where WIMP relic density matches observation

Other Labs are getting into the Game!

APEX looks for A' (new Vector Boson) decaying to e+e-. A' sensitivity from 65 to 550 MeV.



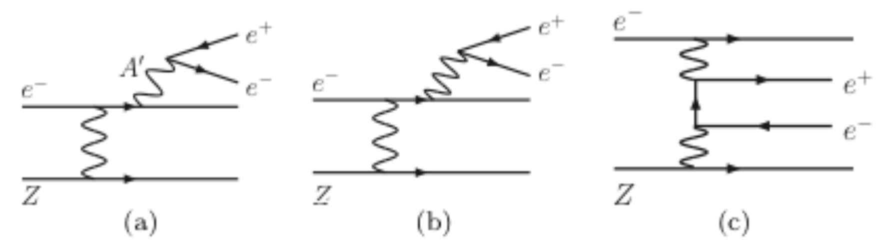
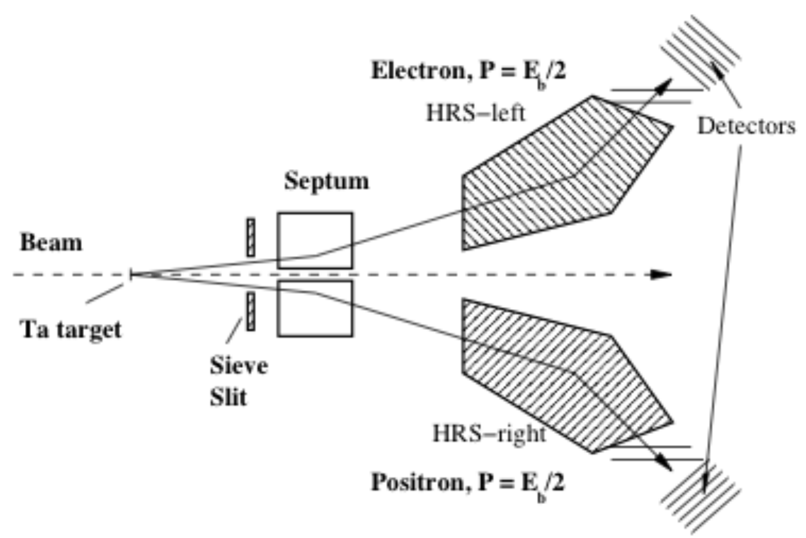
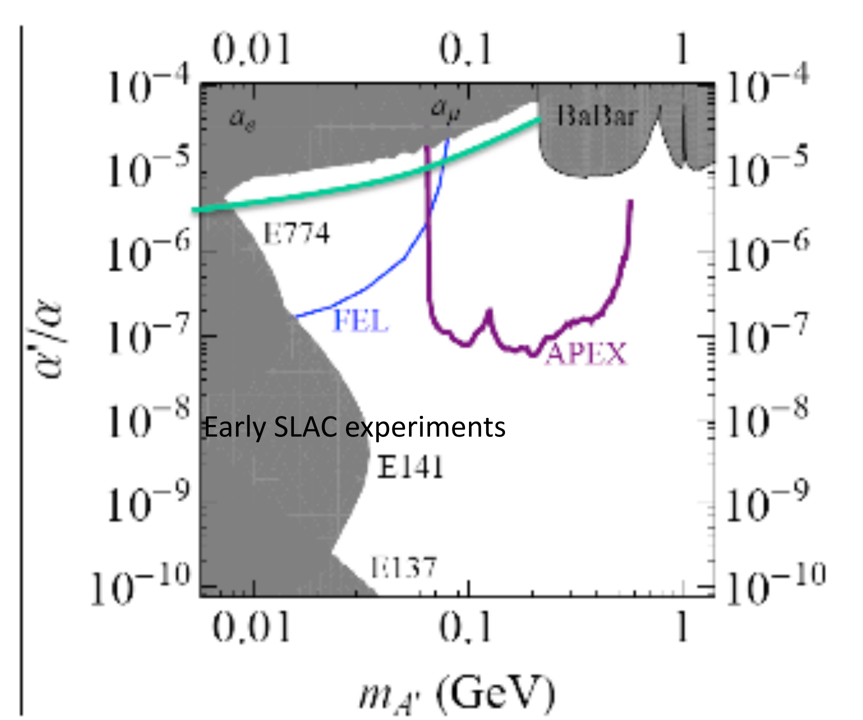


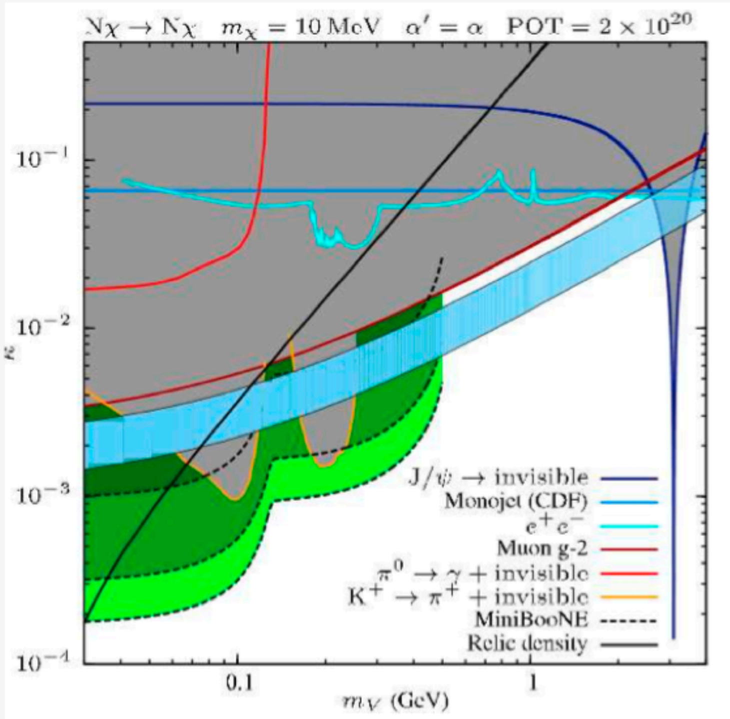
Figure 2: A' signal process (a) and irreducible QED backgrounds (b) and (c).

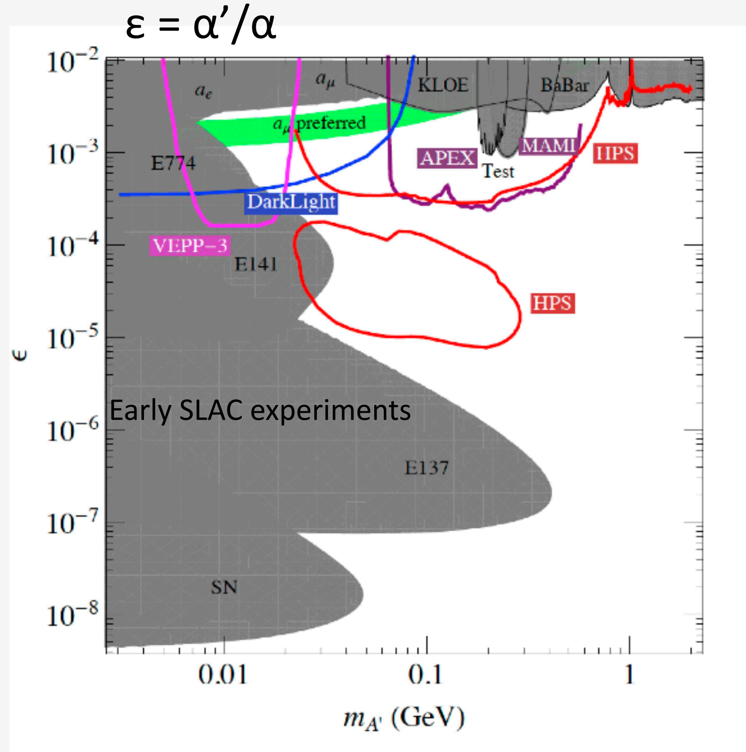


Blue-Green is the muon g-2 band



Two Regimes for Light Mass WIMP Models





$M_v > 2M_{wimp}$
$Br(V \rightarrow SM) \sim \kappa^2\alpha'/\alpha$
“Invisible V decay”

$M_v < 2M_{wimp}$
$Br(V \rightarrow SM) \sim O(1)$
“Visible V decay”

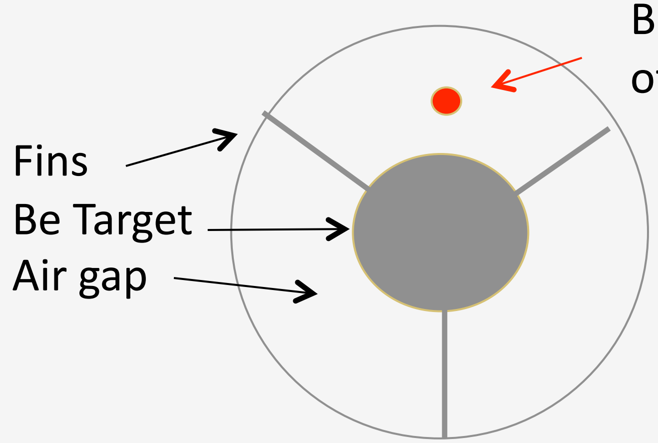
- Limits on the right are significantly weakened when $M_v > 2M_{wimp}$
- Electron and Proton dump experiments compliment each other and extend the search for the hidden/dark sector!
- LSND V->e+e- limits on the right plot, M_v < 100 MeV, and $10^{-4} < \varepsilon < 10^{-6}$

Enhancing the WIMP Search at MiniBooNE

- The WIMP scattering signal looks like neutrino nucleon or neutrino electron elastic scattering. Thus, neutrino interactions are the biggest background to these searches.
- We employ a beam dump type method to significantly reduce charged meson decay, and hence the neutrino flux.

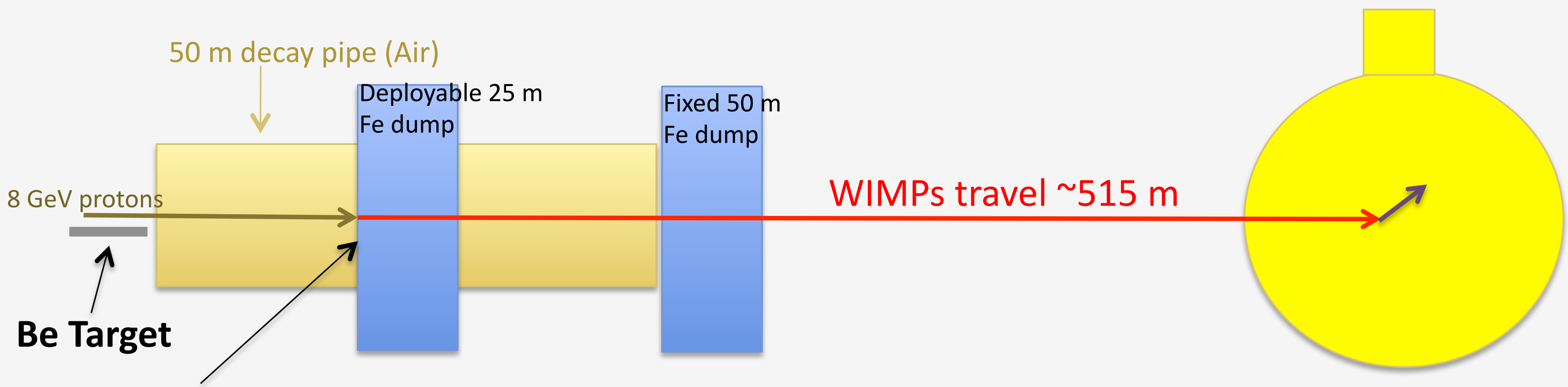
Beam Off Target Running

MB has the capability to steer the protons past the target and onto the 25m or 50m iron dump



Beam spot position in beam off target mode (~1 mm spread)

-Target is 1 cm diameter
-Air gap between target and horn inner conductor is ~1 cm

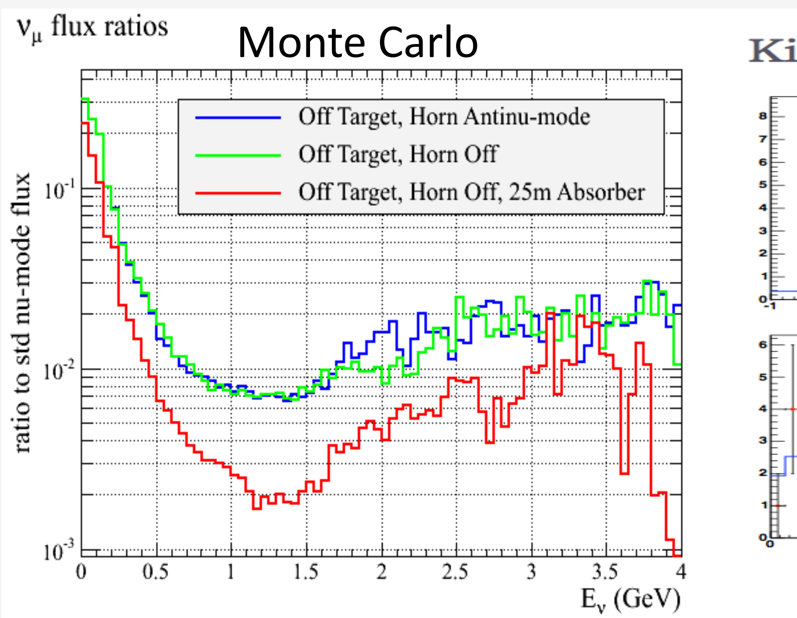


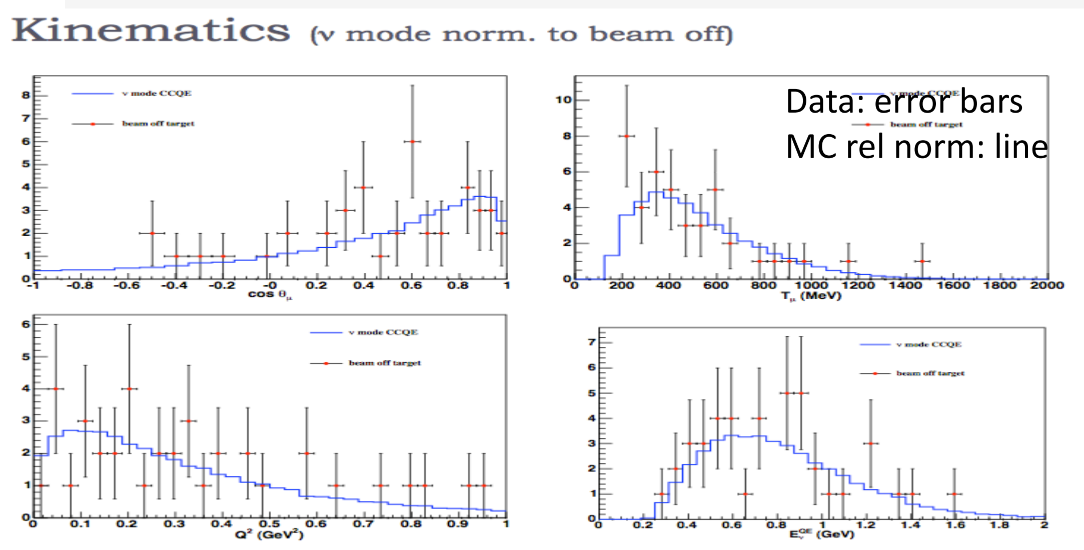
- π^0 and η produced by protons in the iron quickly decay producing WIMPs (χ)
- Charged mesons are absorbed in the iron before decaying, which significantly reduces the neutrino flux (still some production from proton-Air interactions).

Neutrino Rate Reduction with Beam Off Target Running

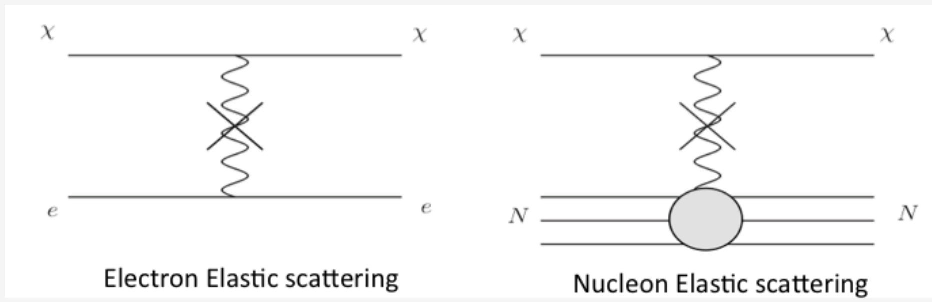
- Estimated neutrino rate reduction:
  - 50m absorber one week beam off target run (~5.54e18 POT):
    $(\text{events/POT})^{\nu\ \text{mode}}/(\text{events/POT})^{\text{beam off target}} = 42 \pm 7$ ← Data rate reduction
  - 50m MC: $(\text{events/POT})^{\nu\ \text{mode}}/(\text{events/POT})^{\text{beam off target}} = 36$
  - 25m MC: $(\text{events/POT})^{\nu\ \text{mode}}/(\text{events/POT})^{\text{beam off target}} = 72$

  ← MC flux reduction (for both MC lines)





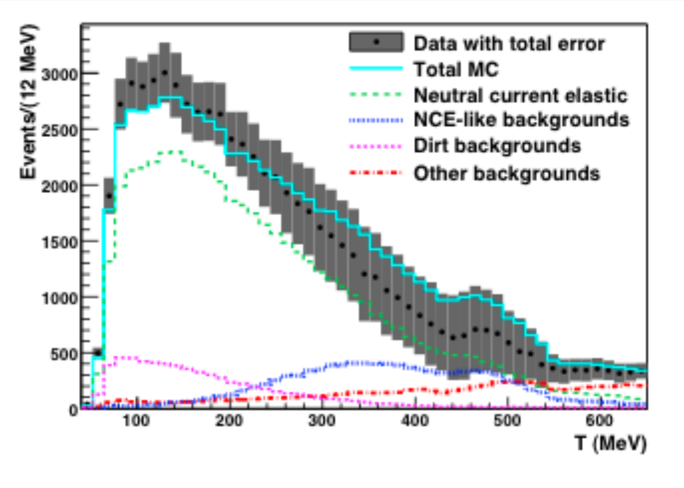
Estimating MiniBooNE WIMP Detection Sensitivities



- WIMPs (χ) can interact in the oil scattering off nucleons and electrons.
  - WIMP events look like neutrino NC scattering off nucleons or electrons but possibly with different kinematics (momentum, angle, timing, etc).
- Can use different techniques to extract signal (there might be more)
  - Neutrino flux reduction (beam off target running)
  - Counting
  - Energy and/or angle fit
  - Timing fit
- Can also use combinations of the above four methods to increase signal over background

WIMP Nucleon Scattering

- MB has already published a detailed neutrino nucleus neutral current scattering result (Phys. Rev. D82, 092005 (2010)).
- Systematic error of 18.1%.
- Cosmic backgrounds not included but effects are small.

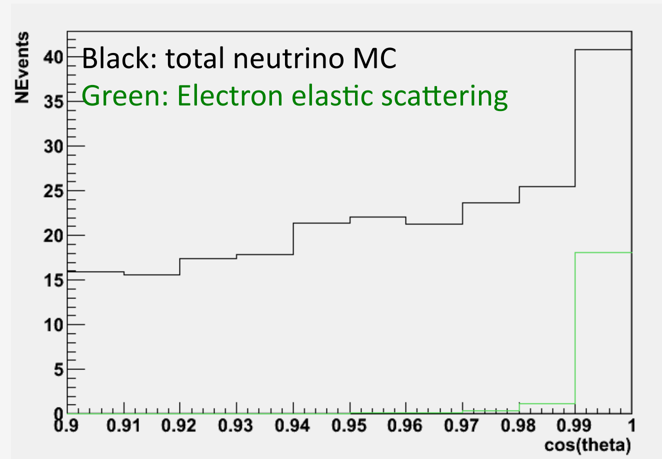


POT	Beam Configuration	25m Absorber ν-Background	25m Absorber 90% U.L.	50m Absorber ν-Background	50m Absorber 90% U.L.
10.1×10^{20}	beam on target antinu			60605	16294
6.5×10^{20}	beam on target nu			95531	22136
6.5×10^{20}	beam off target	1137	267	2275	531
4.0×10^{20}	beam off target	700	166	1400	328
2.0×10^{20}	beam off target	350	85	700	166
1.0×10^{20}	beam off target	175	44	350	85

- PAC request in blue: Estimated neutrino backgrounds and 90% C.L. upper limits

WIMP Electron Scattering

- WIMP-electron scattering is forward peak. With a forward angle cut, can reject 98% of neutrino induced backgrounds.
- Systematic error of 12%.



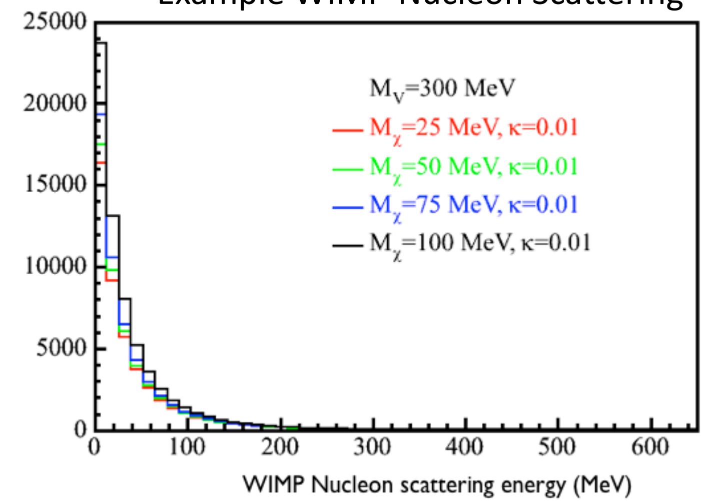
POT	Beam Configuration	25m Absorber ν-Background	25m Absorber 90% U.L.	50m Absorber ν-Background	50m Absorber 90% U.L.
10.1×10^{20}	beam on target antinu			31	8.6
6.5×10^{20}	beam on target nu			41	10.3
6.5×10^{20}	beam off target	0.45	2.75	0.90	3.20
4.0×10^{20}	beam off target	0.30	2.60	0.60	2.90
2.0×10^{20}	beam off target	0.15	2.45	0.30	2.60
1.0×10^{20}	beam off target	0.08	2.38	0.15	2.45

- PAC request in blue: Estimated neutrino backgrounds and 90% C.L. upper limits

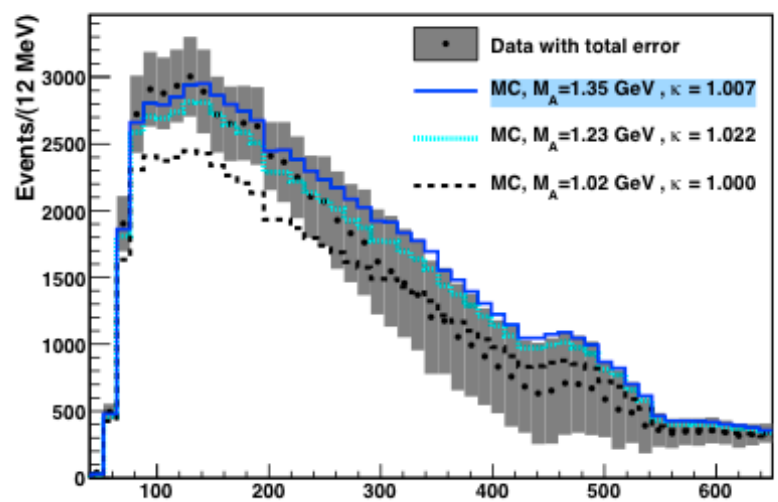
Energy Fit

- Improved sensitivity if the WIMP induced nucleon/electron momentum is significantly different than that of neutrinos.
- We are presently working on these MC estimates and fits using the current neutrino and antineutrino data sets.
  - WIMP event generator needs to be folded into the MiniBooNE MC.
  - Nucleon/electron kinematics depend on M_x, M_V, κ, α'.

Example WIMP-Nucleon Scattering

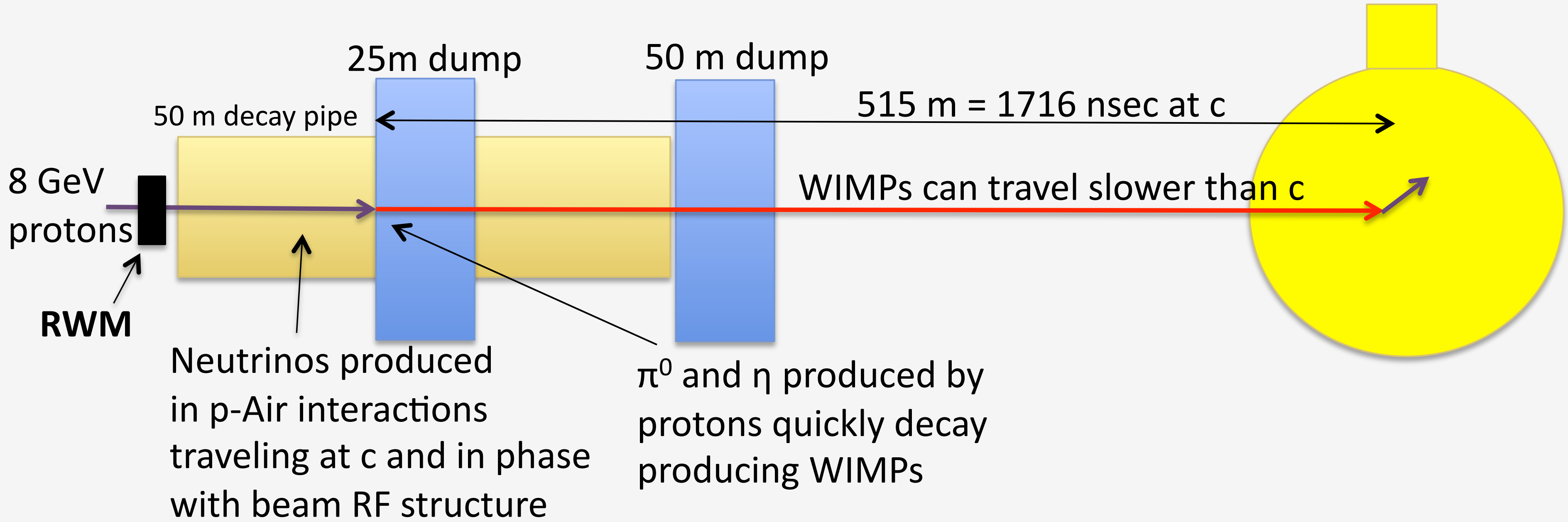


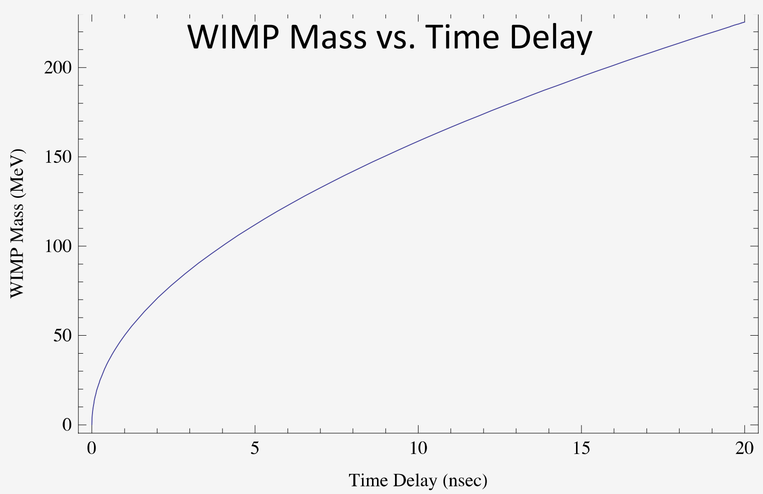
6.5E20 POT neutrino mode



Nucleon Kinetic Energy

WIMP Time of Flight





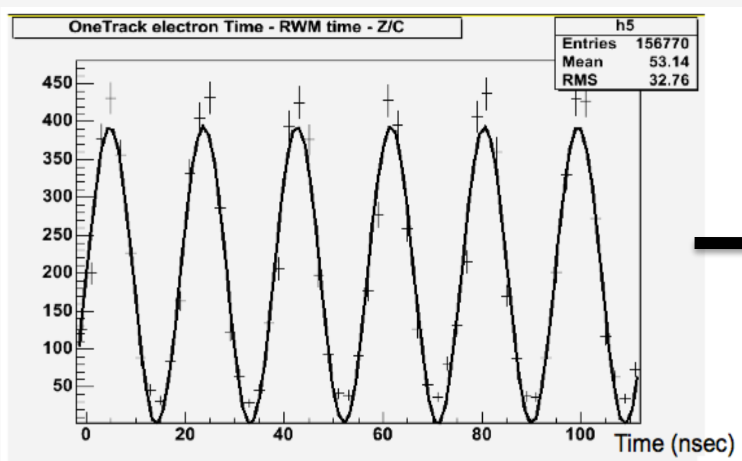
Timing cut (nsec)	Background Reduction (%)	WIMP Velocity β	WIMP Mass (MeV)
3.0	90	0.9984	85
4.6	99	0.9974	108
5.9	99.9	0.9967	122

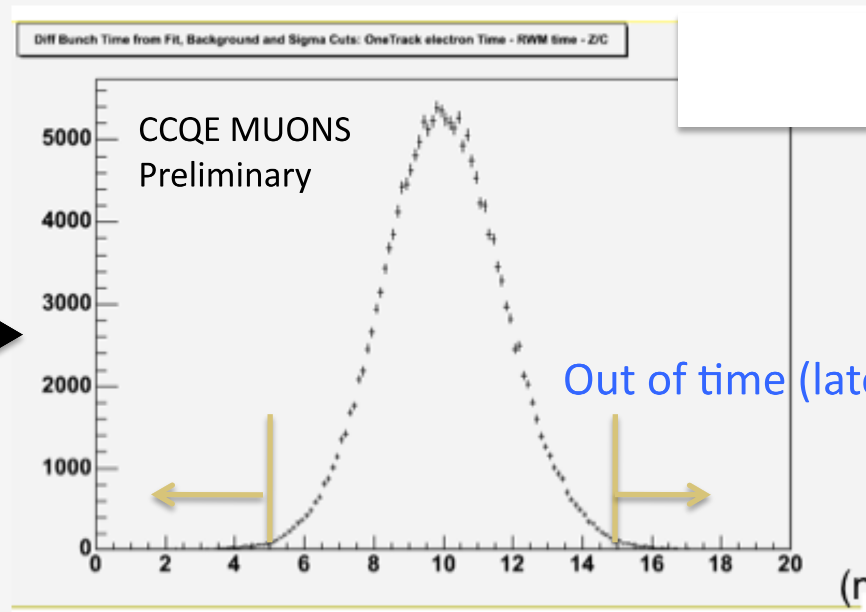
- Absolute beam – detector event timing known to about 1.8 nsec.
- Timing can significantly reject neutrino induced backgrounds for M_x > 50 MeV.

Absolute Timing of Detector Events Compared to RWM

- MiniBooNE 1-sigma absolute event timing relative to the beam is ~1.8nsec in nu mode (worse in antinu mode).
- To achieve 99% rejection of events going at the speed of light, require a 2.58*1.8 nsec= 4.6 nsec timing cut.
  - This results in a 50% efficiency hit to the signal

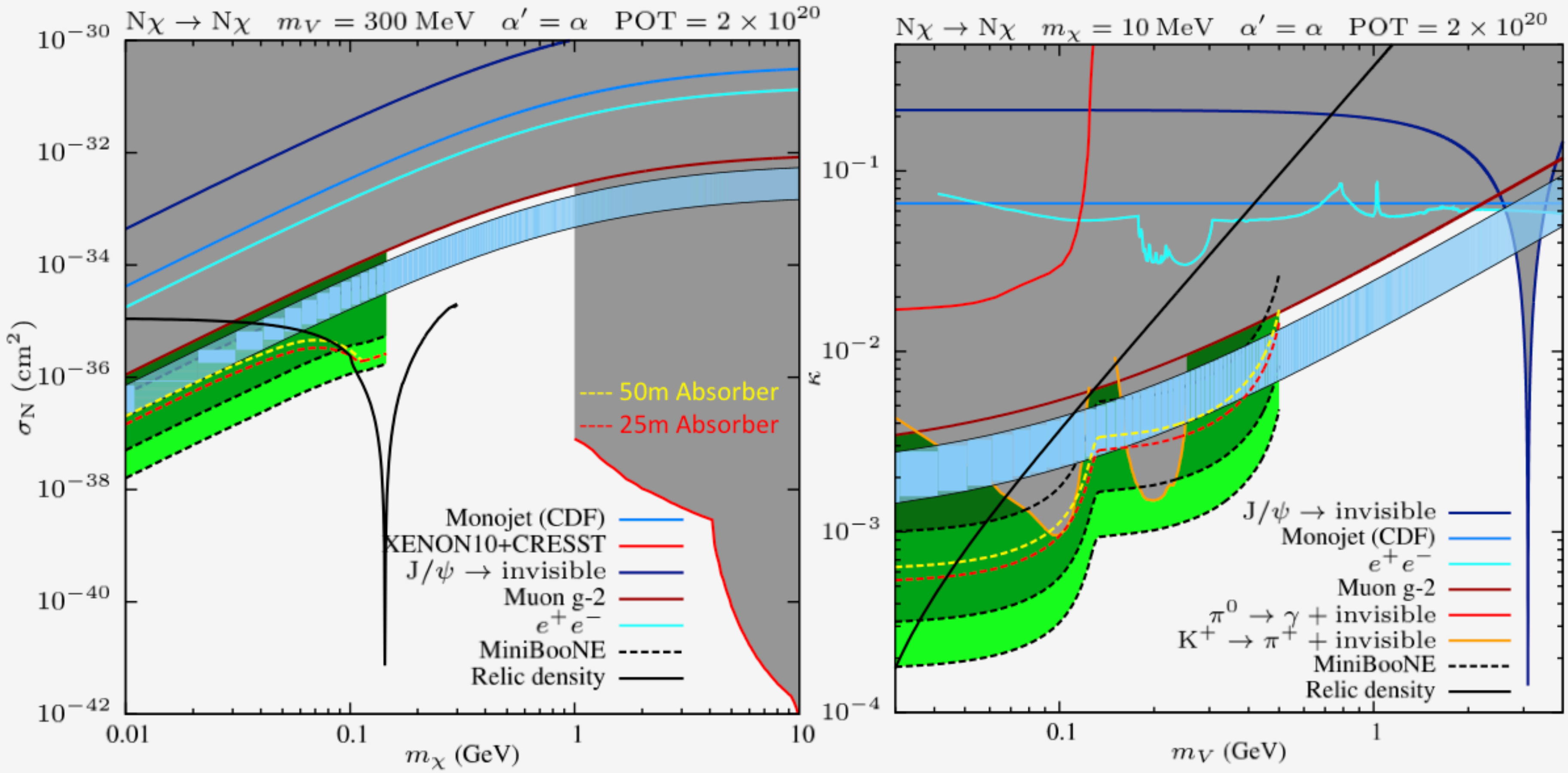
RF buckets





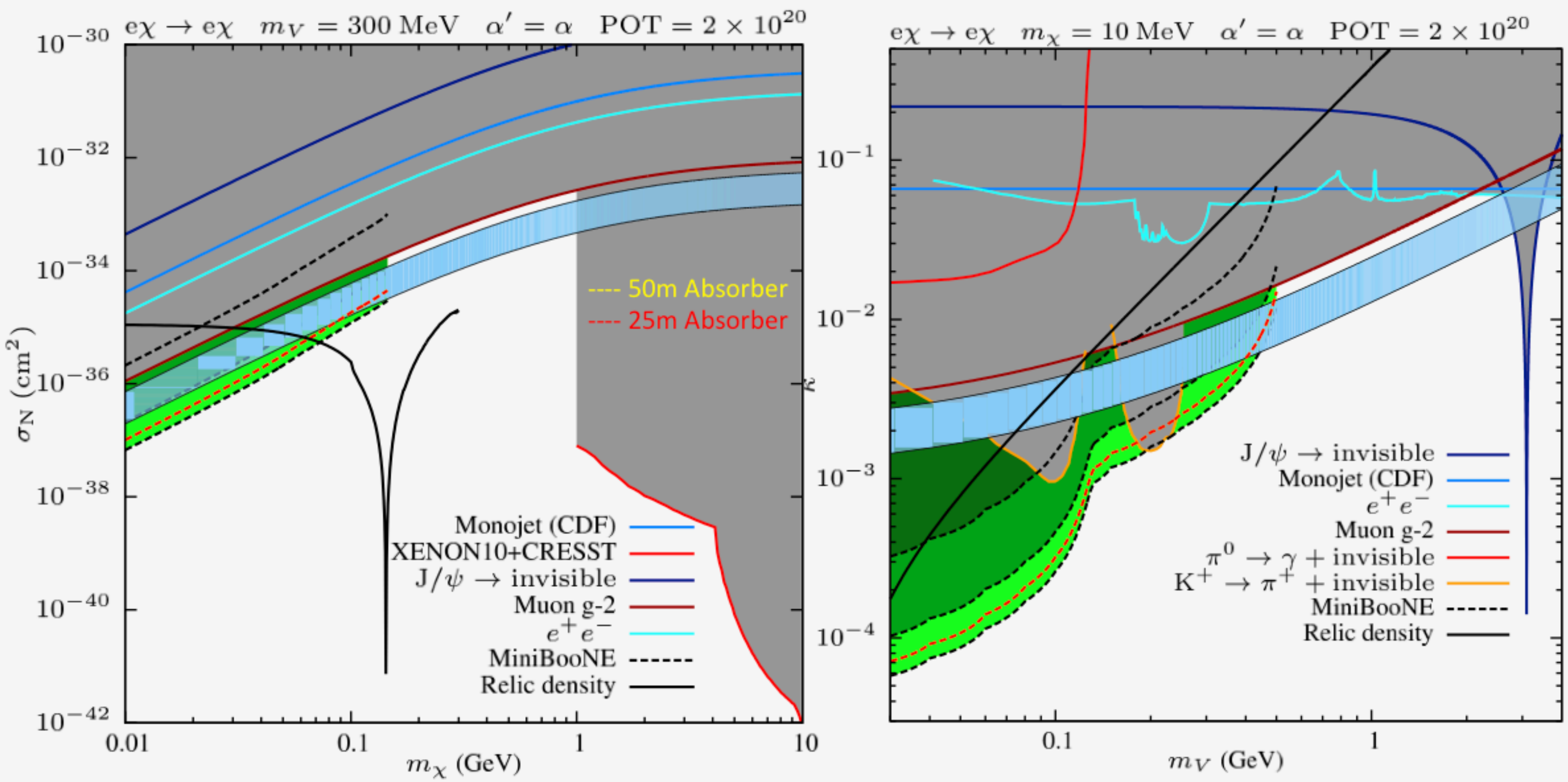
Event Time – Beam Time (all corrections) - nsec

90% C.L. Sensitivities for WIMP-Nucleon Scattering: 2E20 POT Beam off Target and 25/50m Absorber Run



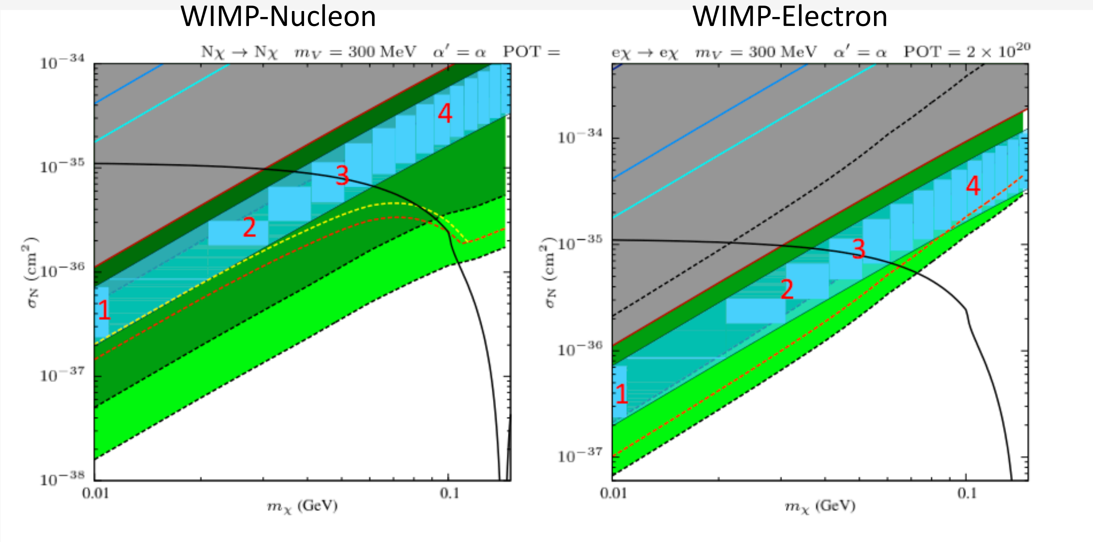
- Estimate 90% C.L. upper limits includes timing information.
- Can cover a significant part of the muon g-2 signal region.

90% C.L. Sensitivities for WIMP-Electron Scattering: 2E20 POT Beam off Target and 25/50m Absorber Run



- Estimate 90% C.L. upper limits includes $\cos\theta_{beam}$ and timing info.
- Can cover a significant part of the muon g-2 signal region.

Estimated WIMP Signal Significance:
2E20 POT Beam off Target and **25m** Absorber Run



- Signal, backgrounds and significance for various M_x and σ points in the g-2 band.
- g-2 band mostly covered at > 5σ

Pt.	Scattering Channel	Beam Mode (2.0×10^{20} POT)	WIMP mass (MeV)/ cross section (cm^2)	Signal	Background and Errors	Probability
1	Nucleon	25m	$10/4 \times 10^{-37}$	1859	350±66	$< 10^{-10}$
2	Nucleon	25m	$30/3 \times 10^{-36}$	1453	350±66	$< 10^{-10}$
3	Nucleon	25m	$50/8 \times 10^{-36}$	1326	203±40	$< 10^{-10}$
4	Nucleon	25m	$100/3 \times 10^{-35}$	1186	9.2±3.4	$< 10^{-10}$
1	Electron	25m	$10/4 \times 10^{-37}$	13.2	0.15	$< 10^{-10}$
2	Electron	25m	$30/3 \times 10^{-36}$	7.7	0.15	$\sim 10^{-9}$
3	Electron	25m	$50/8 \times 10^{-36}$	4.8	0.09	$\sim 10^{-6}$
4	Electron	25m	$100/3 \times 10^{-35}$	1.4	0.004	$\sim 10^{-3}$

Pt. 3 is overlap of g-2 and relic density

MiniBooNE Collaboration Currently Signed up for Beam Off Target Running

The MiniBooNE Collaboration

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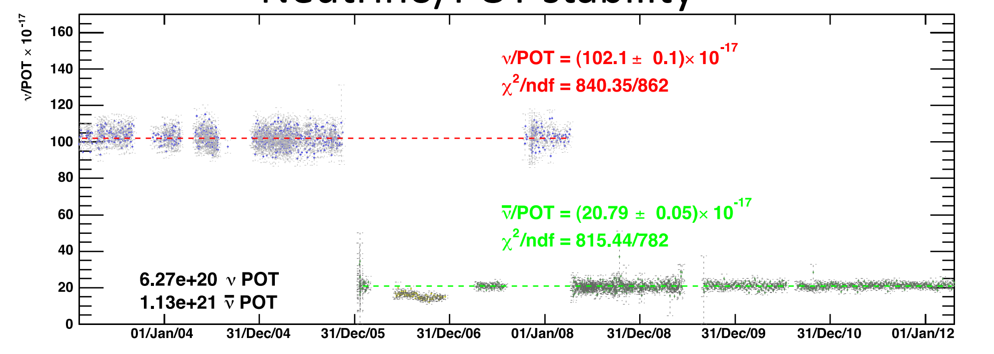
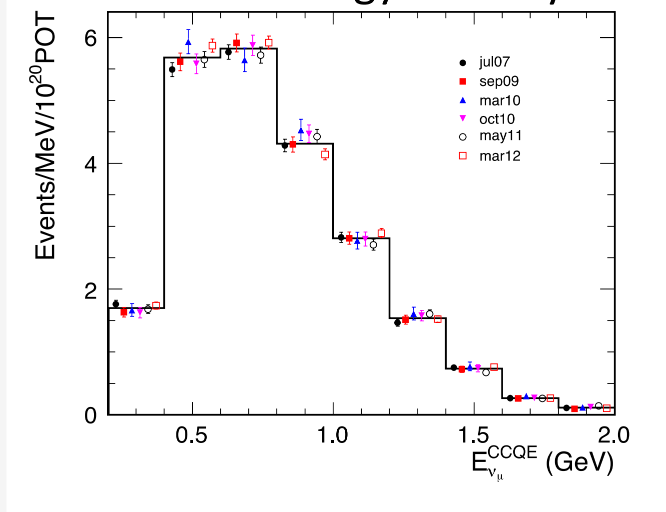
Run Stability and Logistics

- MB running has been stable for 10 years:

Neutrino/POT stability



Muon Energy Stability



- Should continue stable running for the next few years. Will keep the beamline tuned up for MicroBooNE.
- There are sufficient beamline (3rd horn and target) and detector spares. Some upgrades being done (see backup slides).
- The infrastructure costs of further running are relatively small. FTE's required to run almost the same as in shutdown.

The MiniBooNE PAC Request

MiniBooNE requests running to collect a total of 2.0×10^{20} *POT in beam off target mode and with the 25m absorber deployed. This will allow a powerful search for light mass WIMPs in a parameter space that overlaps with muon* $g-2$ *and cosmic relic density estimates. The experiment further requests that this beam be delivered in FY2013 and 2014 before the MicroBooNE experiment turns on.*

- Search for low mass WIMP signals is compelling and explores uncharted territory.
- In the period before MicroBooNE turns on (~1 year), we put the idle Booster Neutrino Beamline (BNB) to good use that will produce publishable physics.

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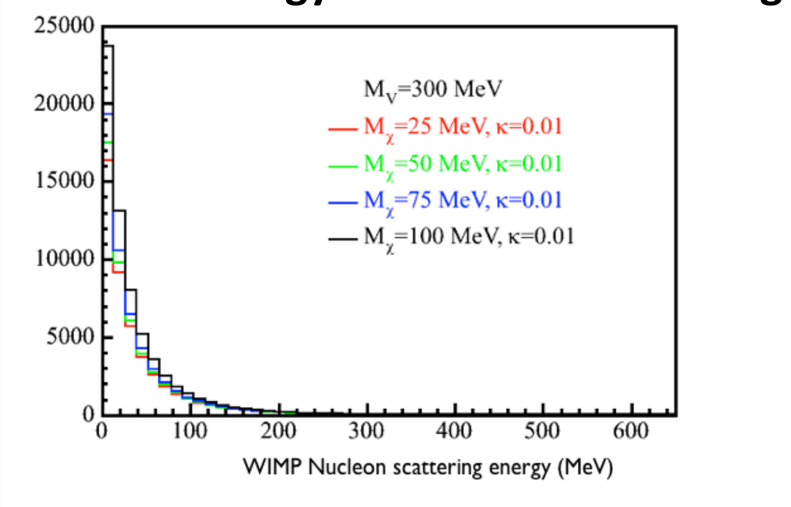
- Search for low mass WIMP signals is compelling and explores uncharted territory.
- In the period before MicroBooNE turns on (~1 year), we put the idle Booster Neutrino Beamline (BNB) to good use that will produce publishable physics.
- Proposal rejected, cited lack of remaining collaboration strength and not completing the WIMP scattering analysis on the current data sets.
  - We were planning to show our latest analysis results in March to again try to motivate the run. However, opportunity knocks now…

FNAL Beamline Commissioning

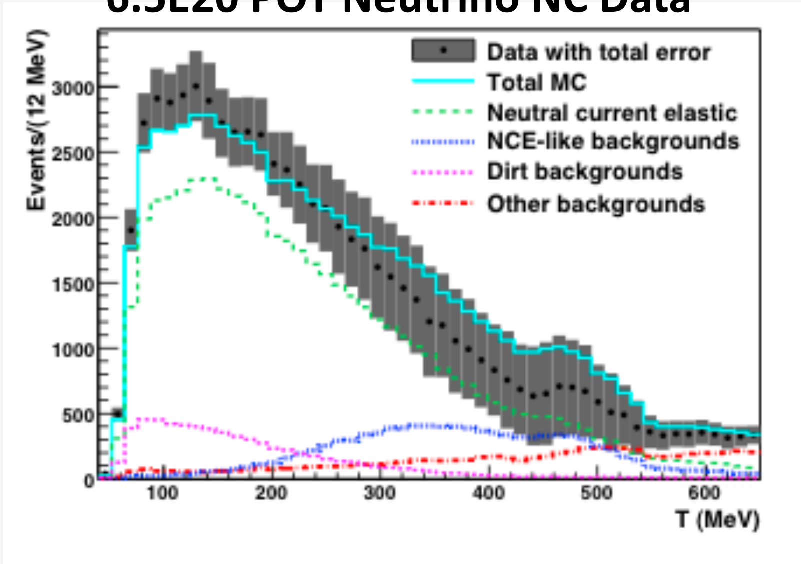
- Spring/Summer of 2013, FNAL is coming out of a long shutdown after major upgrades to the Booster and Main Injector.
- Accelerator Division has brought up the possibility of commissioning the Booster/MI during the summer, and putting the protons on a beam dump.
- What better beam dump than the BNB!!
- This plan also avoids conflicts with NOvA running.
- We recently had a meeting with the FNAL management to discuss this possibility in light of the recent analysis and better understanding of the POT required.
  - They are interested!!!

Work Since the PAC Decision: Using Energy to Fit to the Neutrino NC Data

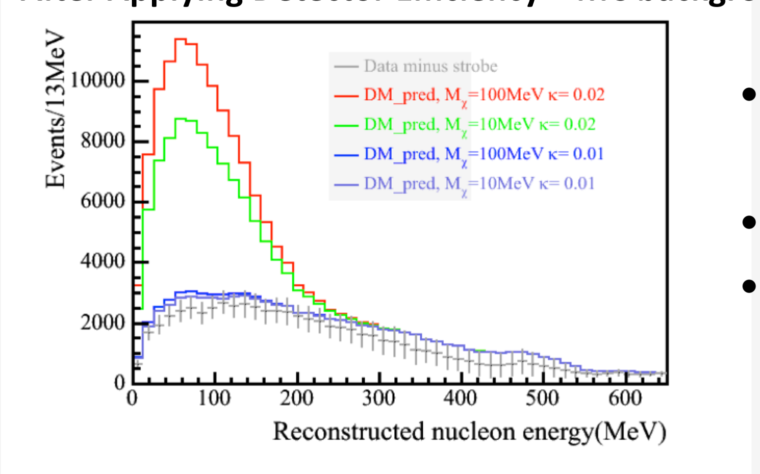
Nucleon Energy from WIMP Scattering



6.5E20 POT Neutrino NC Data

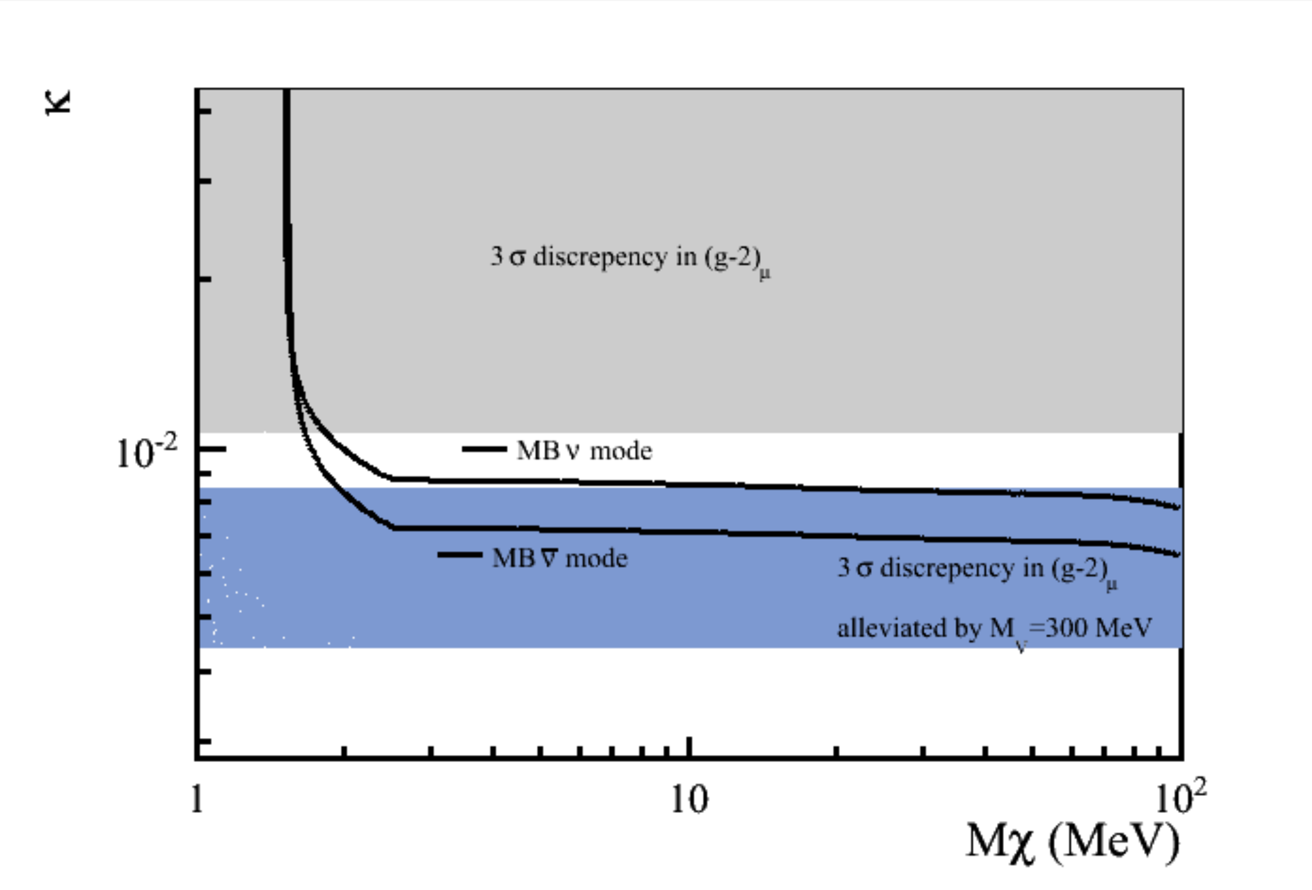


After Applying Detector Efficiency + MC background



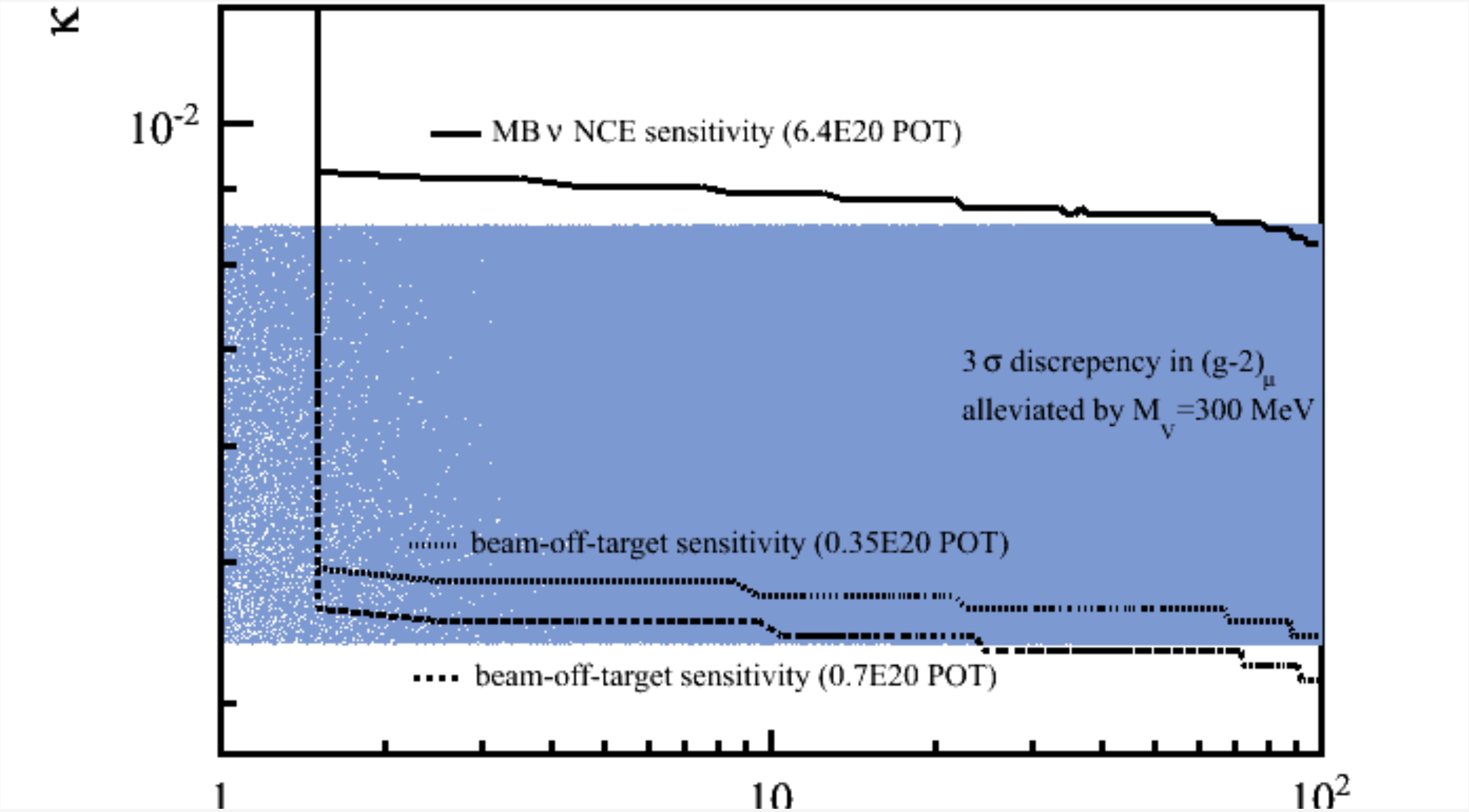
- Fit the WIMP template plus the neutrino background prediction to the NC data.
- Fit for the WIMP mass and cross section
- Most of the WIMP signal resides < 150 MeV.

Limits derived from WIMP Scattering Fits to the 6.5E20POT Neutrino and 11.27E20 POT Antineutrino Nucleon data



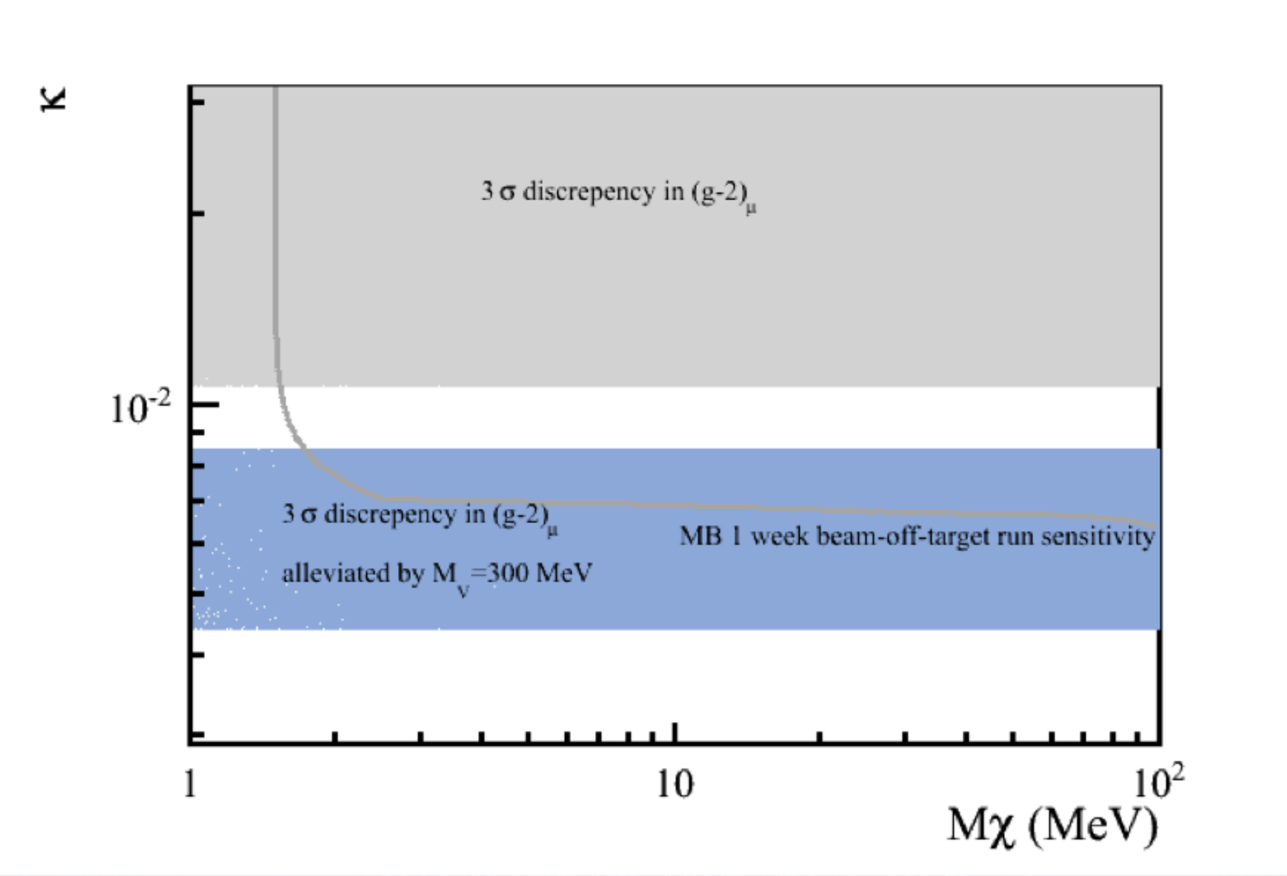
- Limits better than anticipated due to the use of energy. However, still does not completely cover the interesting g-2 signal region.
- Timing analysis is almost complete and will be applied soon.
- WIMP-electron scattering will give best sensitivity, but more work needed to push down energy thresholds below 140 MeV.

What can we do with 0.35E20POT Beam off Target Running and the 50m Dump



- Can cover most of the g-2 signal region with only 0.35E20POT!

Even with the one week 50m dump test run (5.54E18 POT) we have Decent Sensitivity



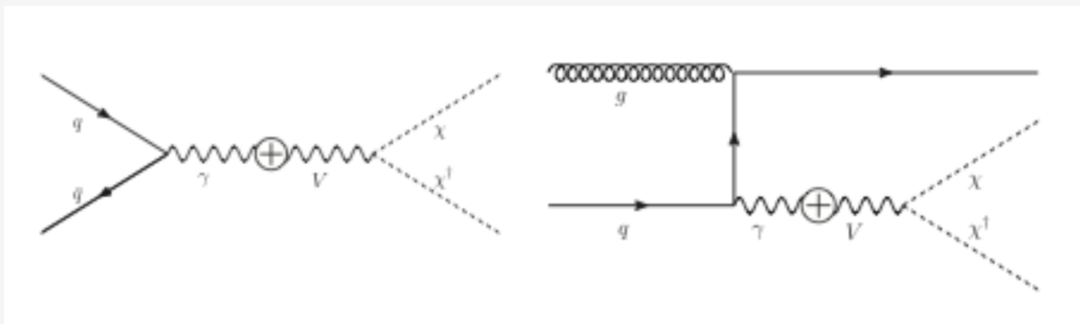
- Along the g-2 band, could expect up to a hand full (~20) of signal events!
- We are currently looking carefully at this data set.

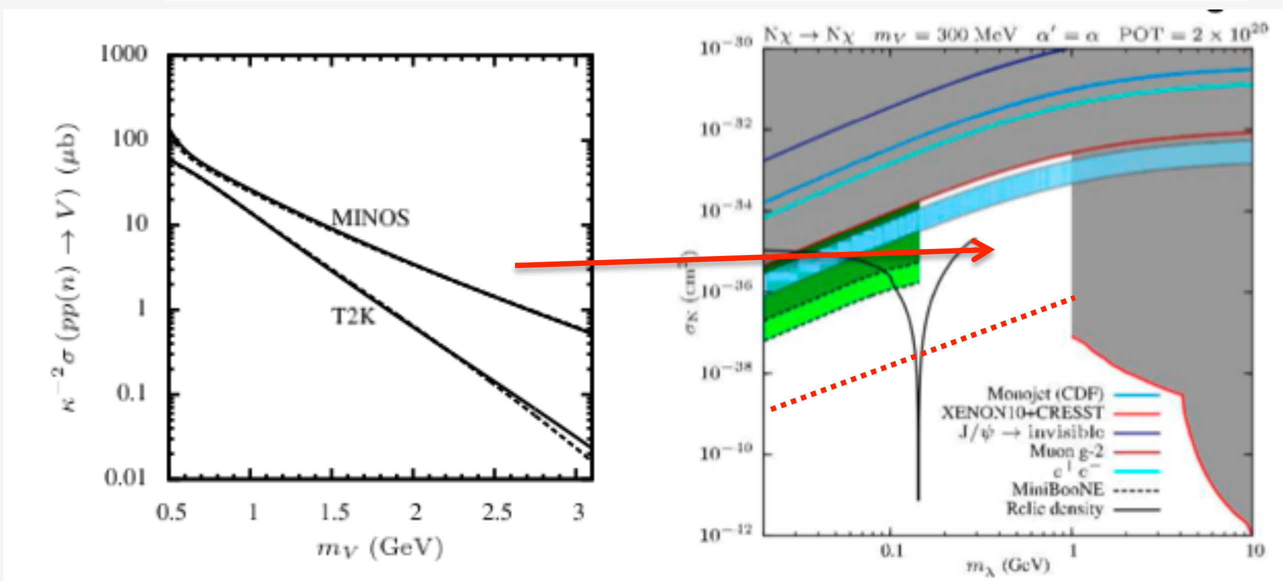
Conclusions 1

- The beam off target run will result in at least >2 papers that will produce relevant WIMP limits (or possibly signals).
  - MiniBooNE sensitivities explores new regions of WIMP parameter space that are consistent with relic density estimates.
  - MiniBooNE explores a region that is a possible explanation for the muon g-2 anomaly. We could play a role in the interpretation of the upcoming muon g-2 run at FNAL.
- The run for 2E20 POT was rejected by the FNAL PAC, however we have gone back to the FNAL management arguing that we can make the search with much fewer protons.
  - An opportunity exits to run while the accelerators are being commissioned
  - We can make relevant and publishable WIMP search with only 0.35E20 POT (~2 months of running).
- JLAB is looking for the vector mediator (APEX) assuming $M_v < 2M_x$
  - this is just a different aspect of the same dark sector low mass WIMP models we are probing here.
  - FNAL can get into the game for almost free, with only a two month run!

Extending the WIMP search using the Main Injector

- With the higher energy protons (120 GeV), the direct production channel dominates.





- With MI protons we can fill in the M_x gap up to the direct detection experiments, and go lower in cross section!

Developing Proposal for MI and Project X

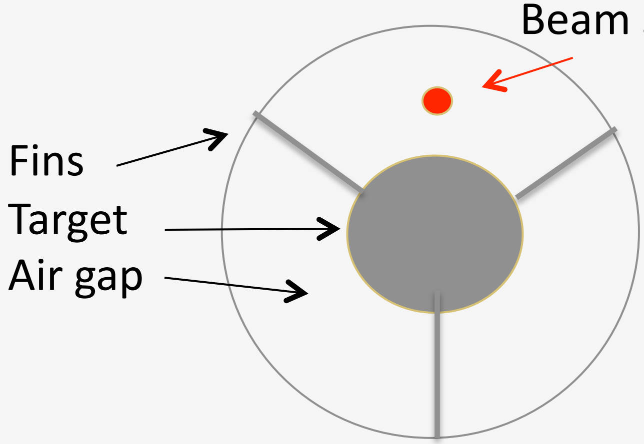
- We would design/build a dedicated beam dump (NuMI cannot run in beam off target mode).
  - With a better design, we could suppress the neutrino flux by more than a factor of 100!
  - The dump needs to take a significant amount of power >100 kW!!
  - Pay attention to improved beam timing.
- Develop a high spatial/timing resolution fiber scintillator detector. Require about 100 tons.
  - 3mm spacing, with ~250 picosecond timing. ~1 MeV threshold.
  - Expensive, 300x/volume more that liquid scintillator detector. Need to drive down cost!!
- Takes advantage of Project X, which will deliver more protons to the Main Injector.

Conclusions 2

- The MiniBooNE beam off target run can help motivate future beam dump experiments and Project X
  - We are working with the intensity frontier group (IF5 – New Light, Weakly Coupled Particles) who are eager to make this a point in the Snowmass 2013 white paper. Progress is good!
  - MI 120GeV protons can extend the WIMP search up to ~1 GeV, which is where the direct detection experiments lose sensitivity.
  - Project X is a natural machine to search for the hidden/dark sector, this needs to be highlighted as a justification for the machine.
- If you are interested in join the new collaboration, let me know…

BackUp Slides

Beam Off Target Running Issues



-Target is 1 cm diameter
-Air gap between target and horn inner conductor is ~1 cm

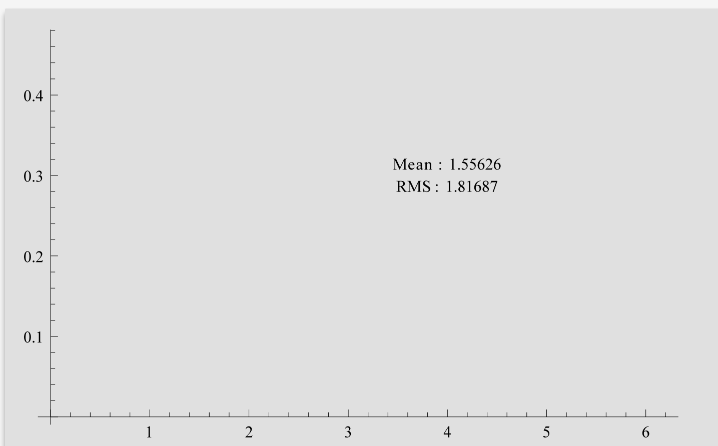
- Successfully ran beam off target on 50 m dump for 1 week in March, 2012.
  - Rad safety reviewed beam dump safety documents and gave the okay.
  - Autotune can keep beam off target with ~1mm spread.
  - No radiation alarms or beamline monitoring anomalies.
  - No risk to the horn from spray as donut collimator would prevent extremely off target beam from hitting the horn.
- For a 12 month run we would turn off the horn, reducing fatigue/stress.

Assumptions on 90% C.L. Upper Limits

- Include statistical and systematic errors on background estimates.
- In the limit of small signal (N_s) and large backgrounds (N_b), 90% upper limits is
  - 1.28*sqrt(N_b + (SysErr*N_b)**2)
- In the limit of zero signal and small backgrounds, the Poisson 90% upper limit is
  - 2.3 events

Mass Threshold for 4.6nsec Time Cut

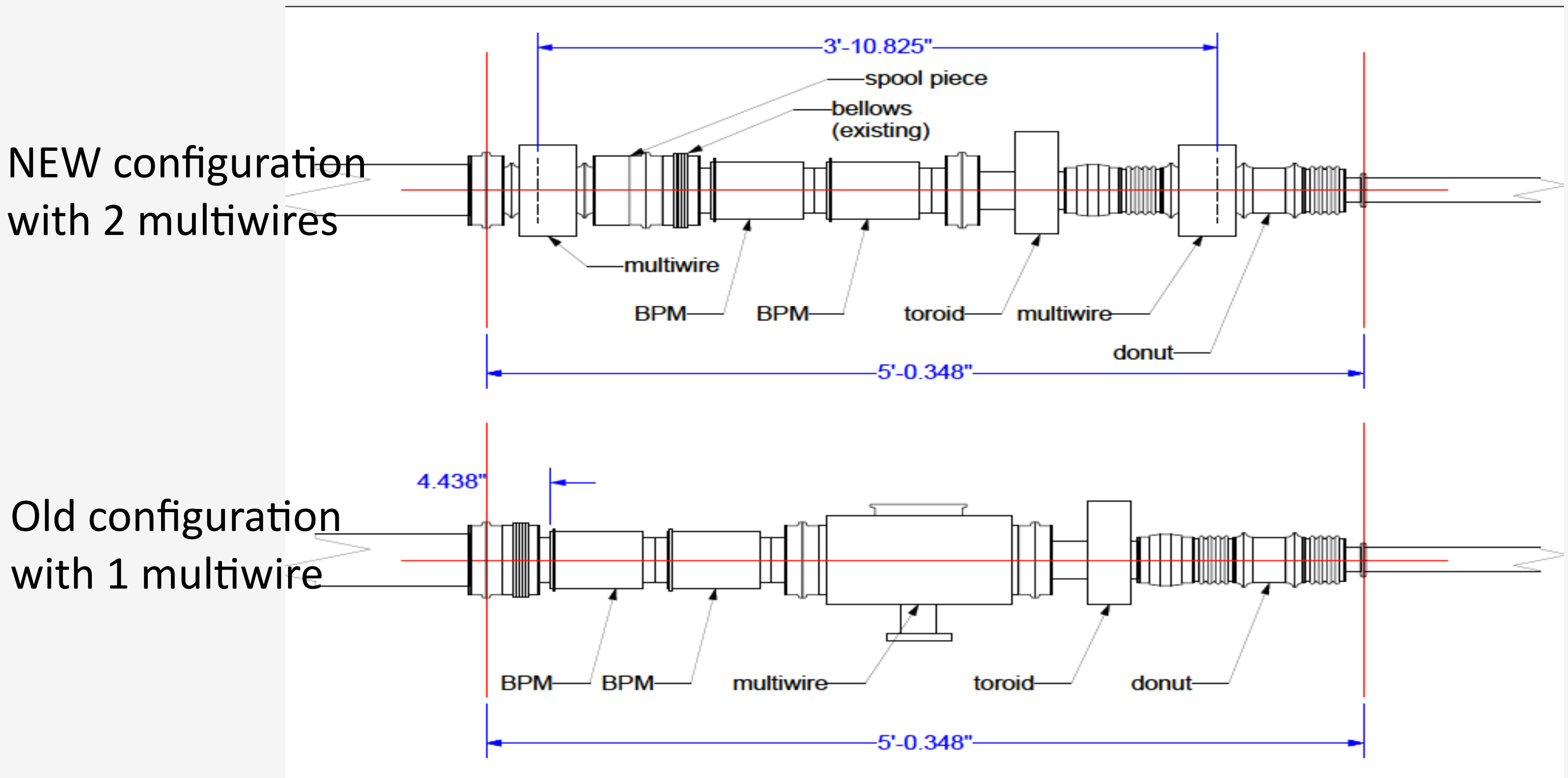
- Based on WIMP kinetic energy distribution, we can assume ~1.5 GeV wimp momentum, then M_t= 108 MeV.
  - Above this mass we can reject neutirno backgrounds by 99%.
  - Coupled with beam off target running, we can achieve 90% limits at the few event level.
  - Using more sophisticated analysis can set limits as a function of WIMP mass for realistic momentum distribution



WIMP momentum for
Mx= 100 MeV and Mv= 300 MeV

GeV

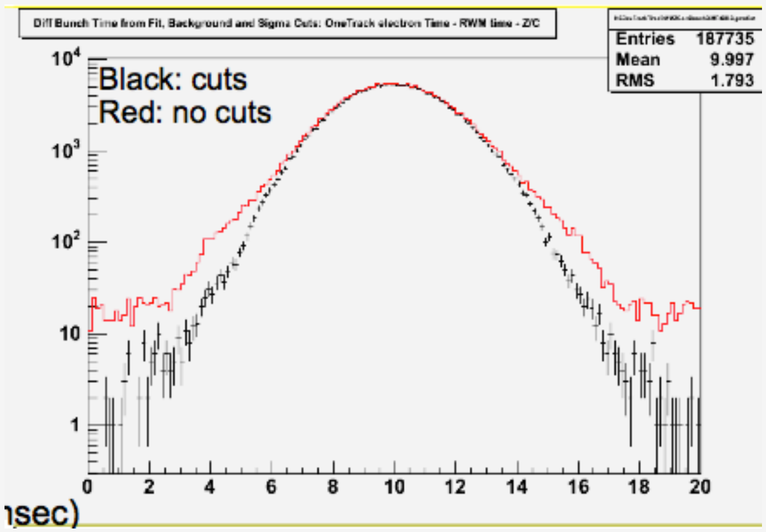
Upgrades to Beam Positioning



- With new dual low mass multiwires, will be able to reliably point the proton beam at the detector to within 0.5 mrad, or about 25 cm spatial resolution.

RWM Timing Upgrades

- Installing new fiber timing circuit between target RWM and the detector electronics.
  - Will result in more stable operation and improved timing.



With old RWM we have to make various quality cuts to remove tails. This created some timing bias which we are trying to understand and quantify. Effect worse in antinu mode.

- We are working with AD to install a wave form analyzer to digitize the RWM RF structure and stored via ACNET.
  - This will provide detailed RF timing structure from pulse to pulse.

Preference is to Run Beam off Target in 25m Absorber Mode

- Pros:
  - Increases the neutrino flux reduction by a factor of two!
    - Improved sensitivities and signal significance.
    - Insurance against less POT delivery.
  - The 25m iron blocks are solid with no cracks. The 50m dump has cracks, if the beam is positioned on the cracks we would not know it and could alter flux reduction profile.
  - 25m dump has imbedded muon monitors for tracking proton direction angles.
- Cons:
  - Cost $80k and 2.5 weeks to deploy. Also, need to bring absorber back up if MicroBooNE runs in 50m mode.

Dark Matter: Where to Look?

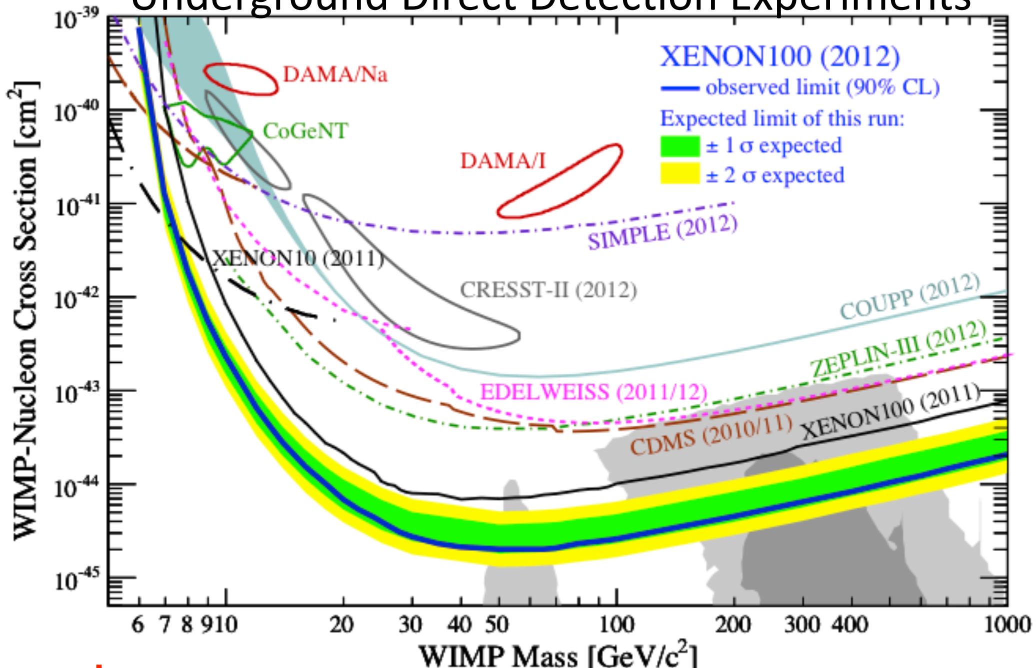
Nuclear Recoil too Weak

$$v_{\rm DM} \sim 10^{-3}c$$

Find a Relativistic DM Beam

What about over here?

Underground Direct Detection Experiments



Lee-Weinberg Bound: SM mediator implies $m_{\rm DM} \gtrsim {\rm few\ \ GeV}$ $(W,\ Z,\ \ldots)$