MiniBooNE Beam Overview

Performance in the First Decade and Plans for the Second

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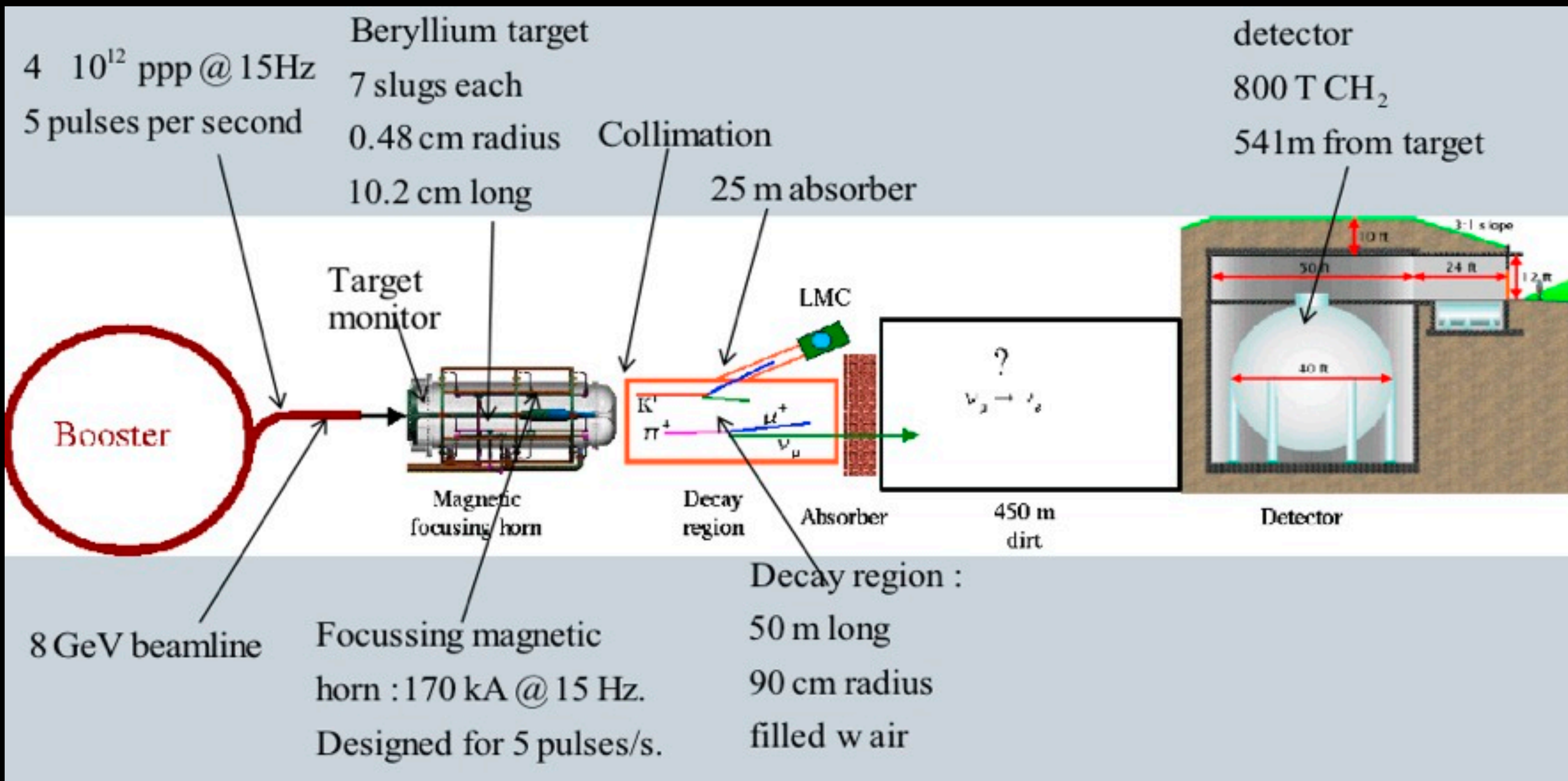
Booster Neutrino Beam Overview

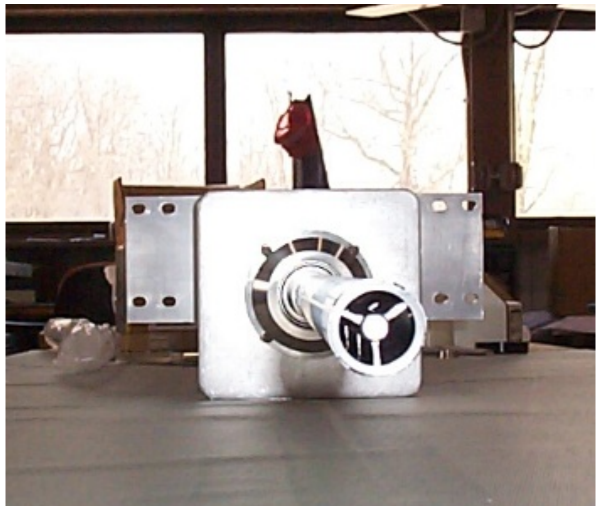


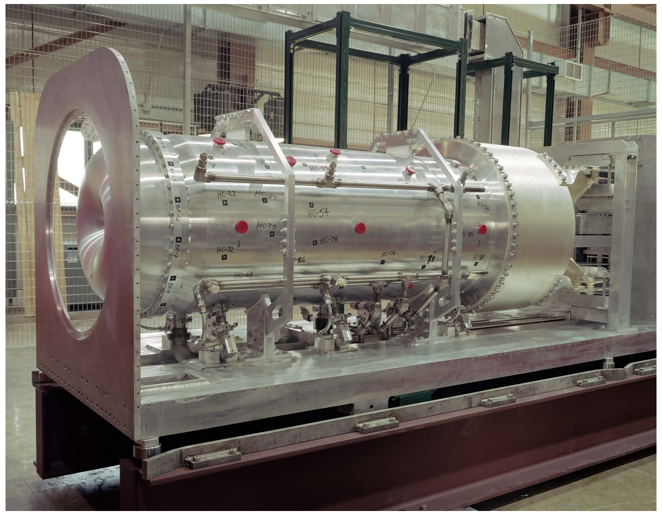
- Designed and built (at FNAL) to test the LSND observation of oscillations via $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance.

Target and Horn

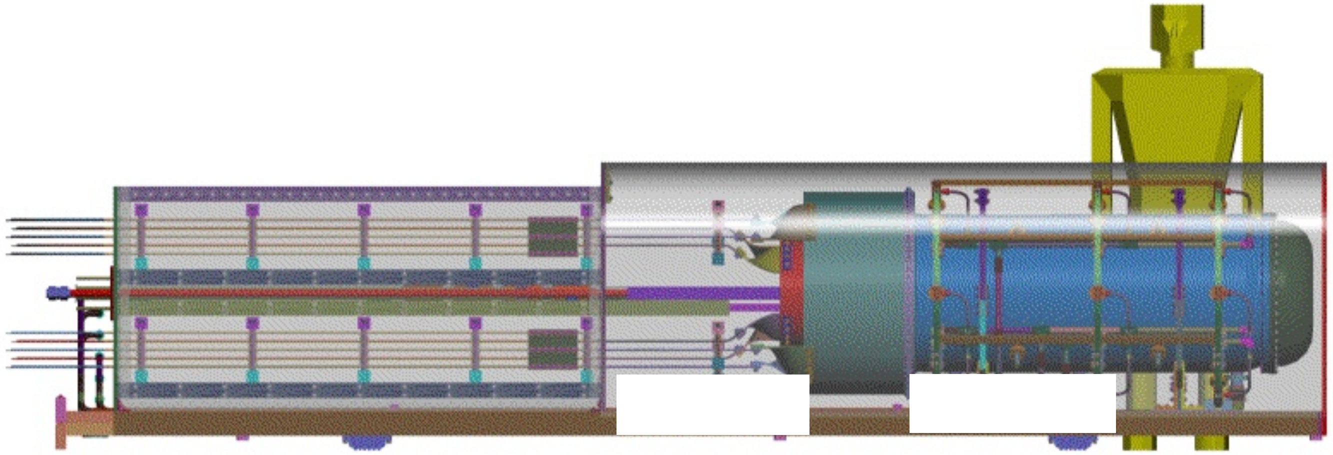
The horn focuses secondary particles produced in the Be target using a torroidal magnetic field.

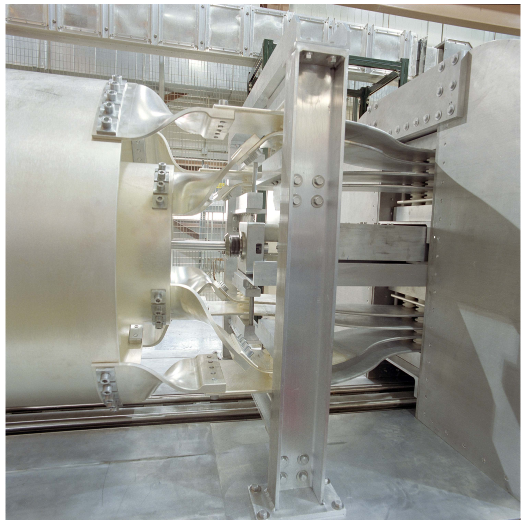
170kA for 140msec @ 5Hz.





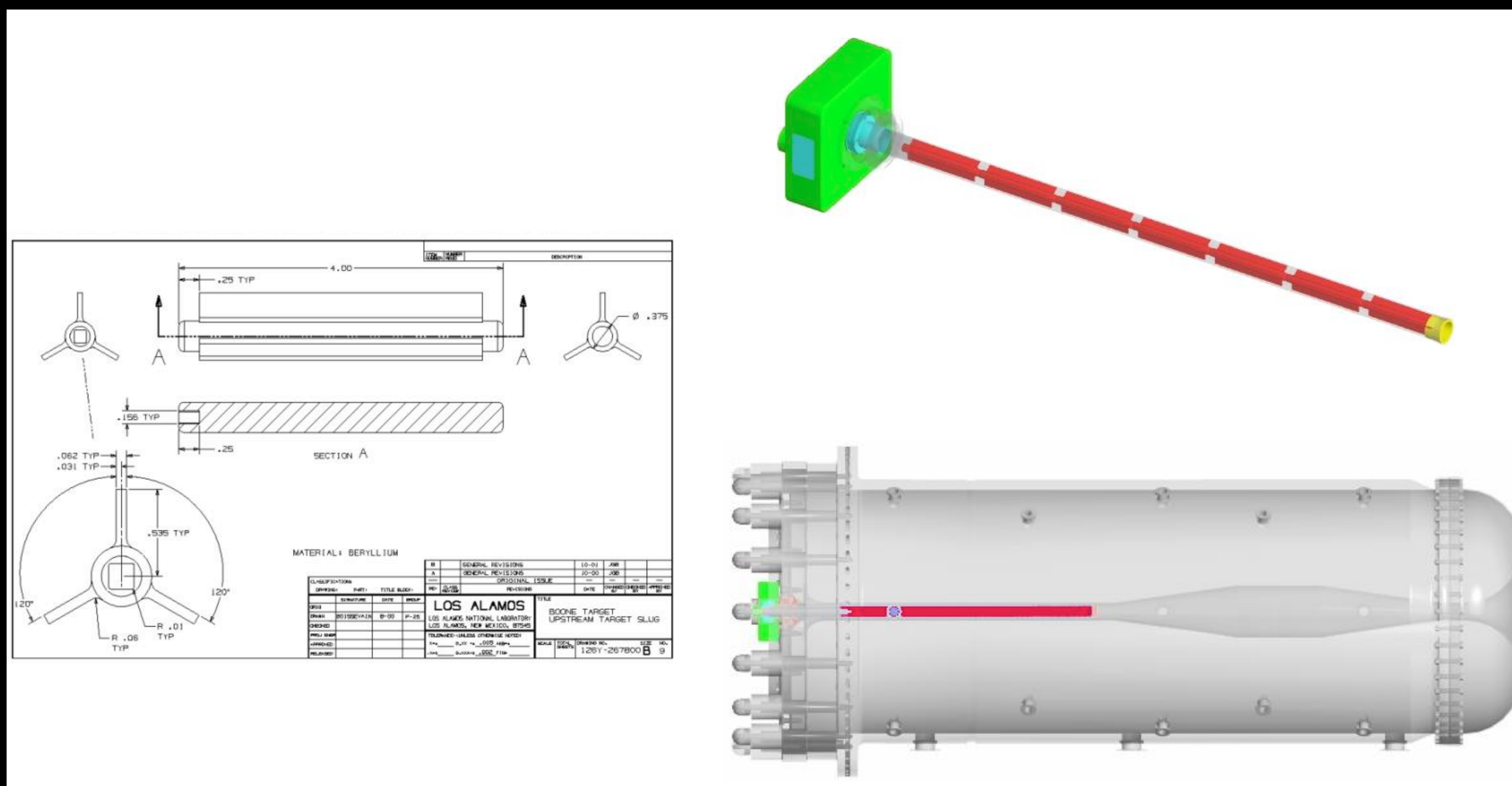
- 53 x 10^6 pulses on horn 1 (correctable water problem)
- 324 x 10^6 pulses on horn 2 and counting…



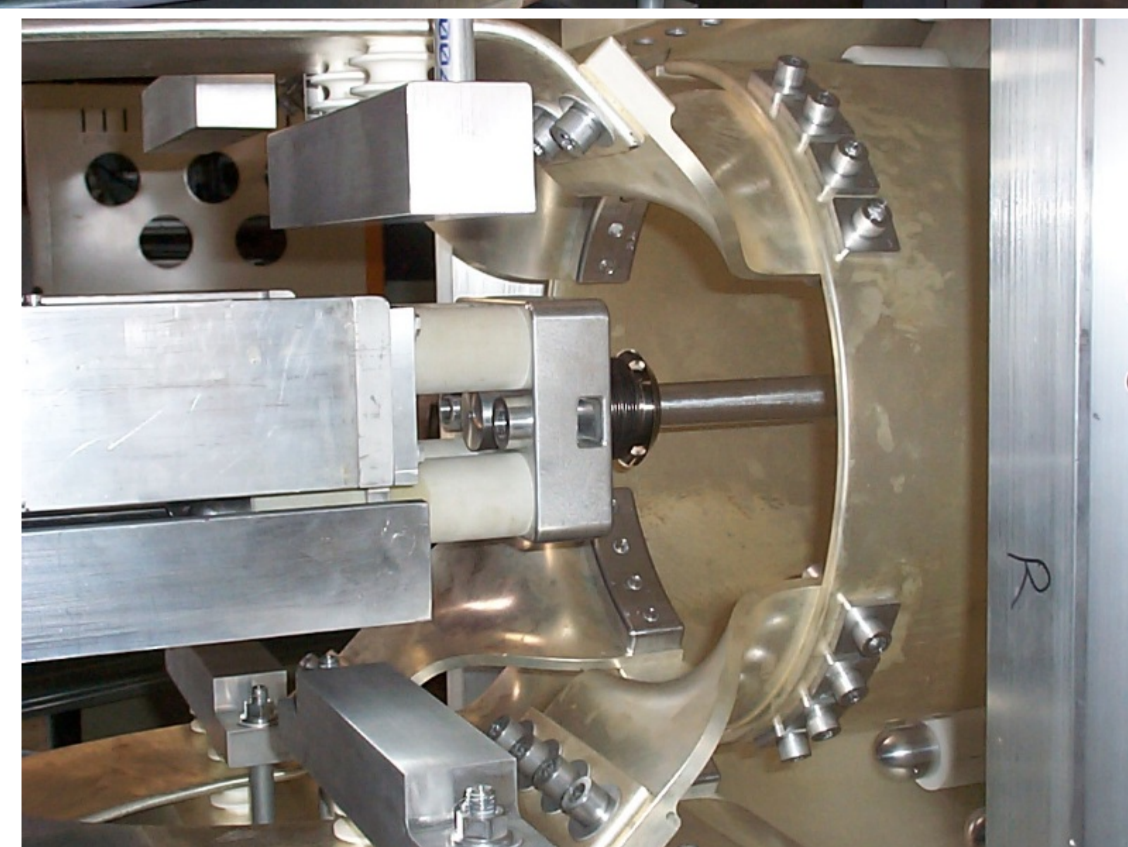


Target Design

- Segmented metallic beryllium target with “fins”
- Air cooling



Horn and Target Gallery

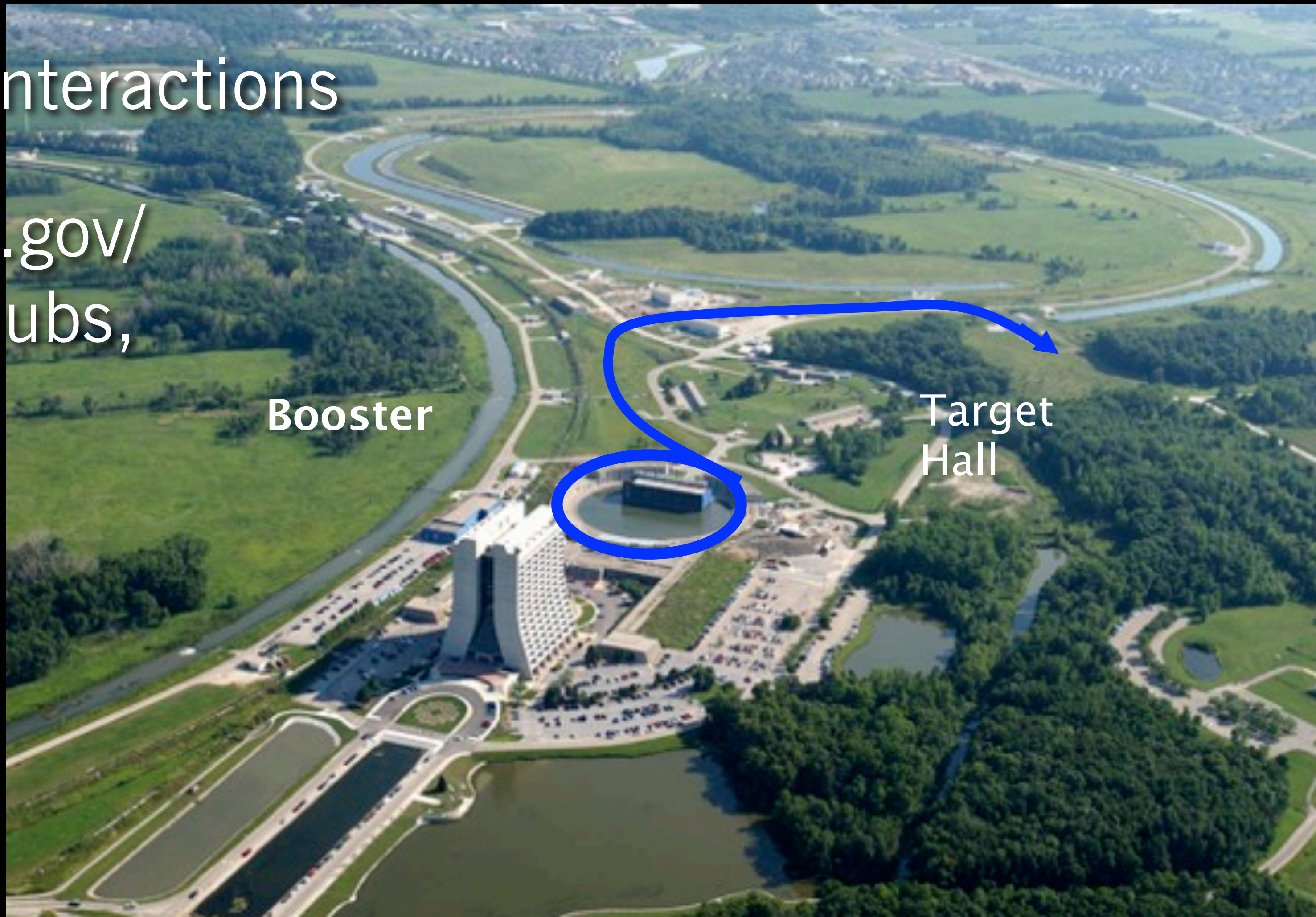


Decay pipe and beam absorber

- Corrugated steel decay pipe, 91 cm (3 ft) radius
- Backfilled, covered with gravel aggregate
- Beam absorber made of stacked steel “blue blocks”

MiniBooNE Beam Overview

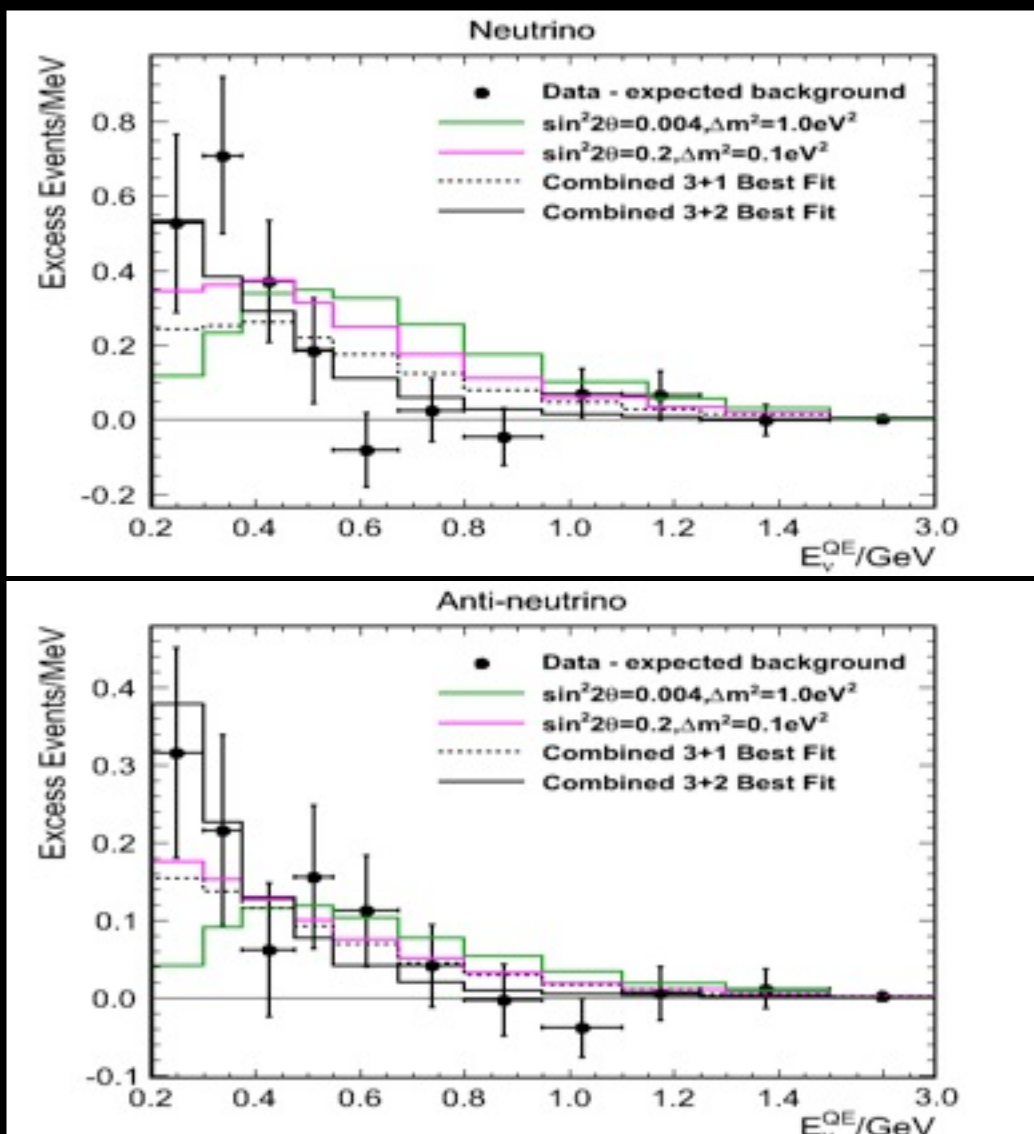
- Recently completed runs:
  - ν_μ mode: 2002-2005, 2007
  - $\bar{\nu}_\mu$ mode: 2005-2006,2008-2012
- Results on oscillations and ν interactions
  - (see http://www-boone.fnal.gov/publications/for full list of pubs, including theses)

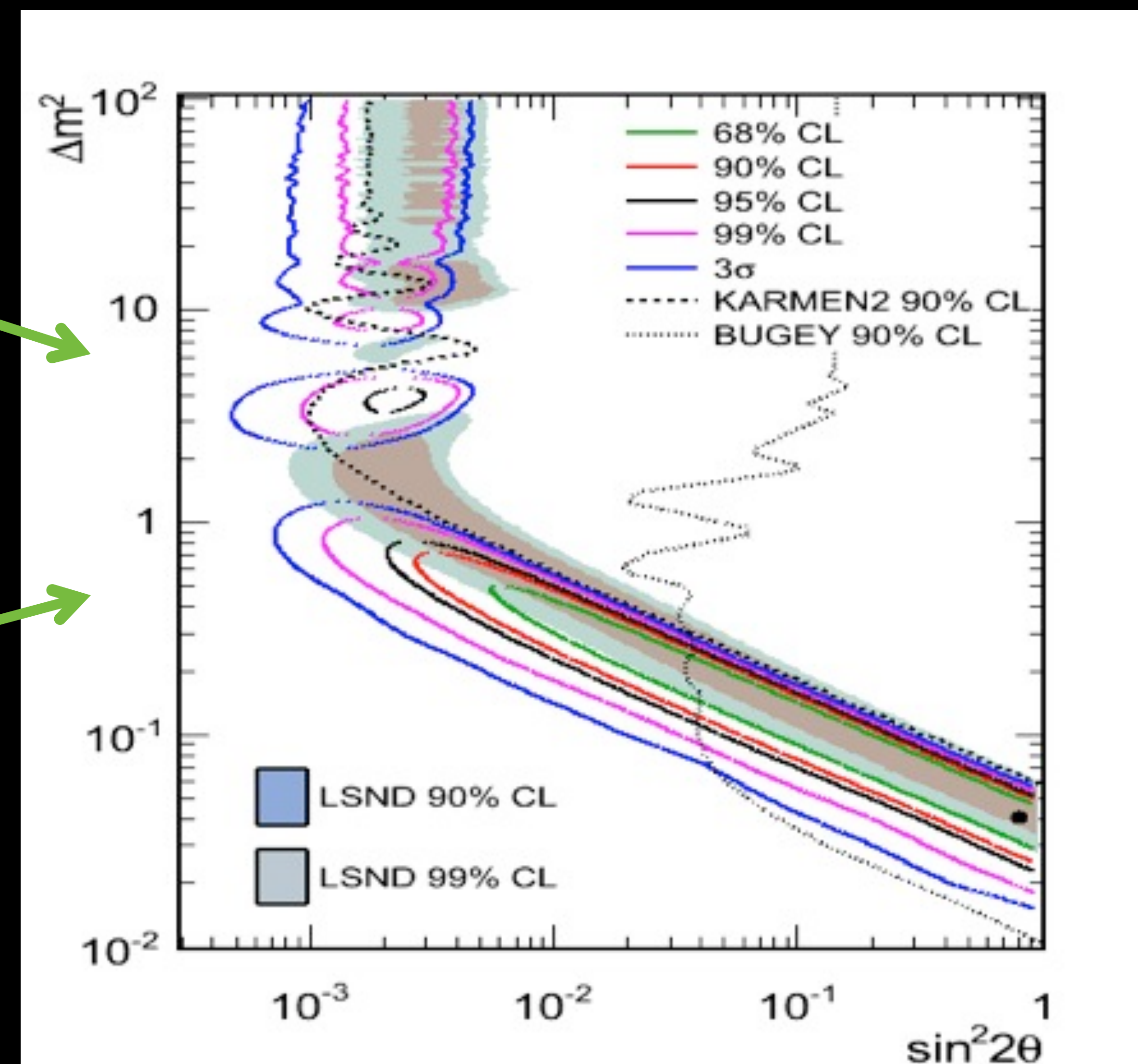


Ten Years of Successful MiniBooNE Running and Results!

- Neutrino mode: 6.5E20 POT
- Antineutrino mode: 11.3E20 POT
- Special horn runs: 0.3E20 POT
- 10 oscillation papers
- 12 cross section and flux papers
- 1 detector and 1 supernova search paper
- 17 PhD thesis
- The experiment has achieved its run and physics goals!

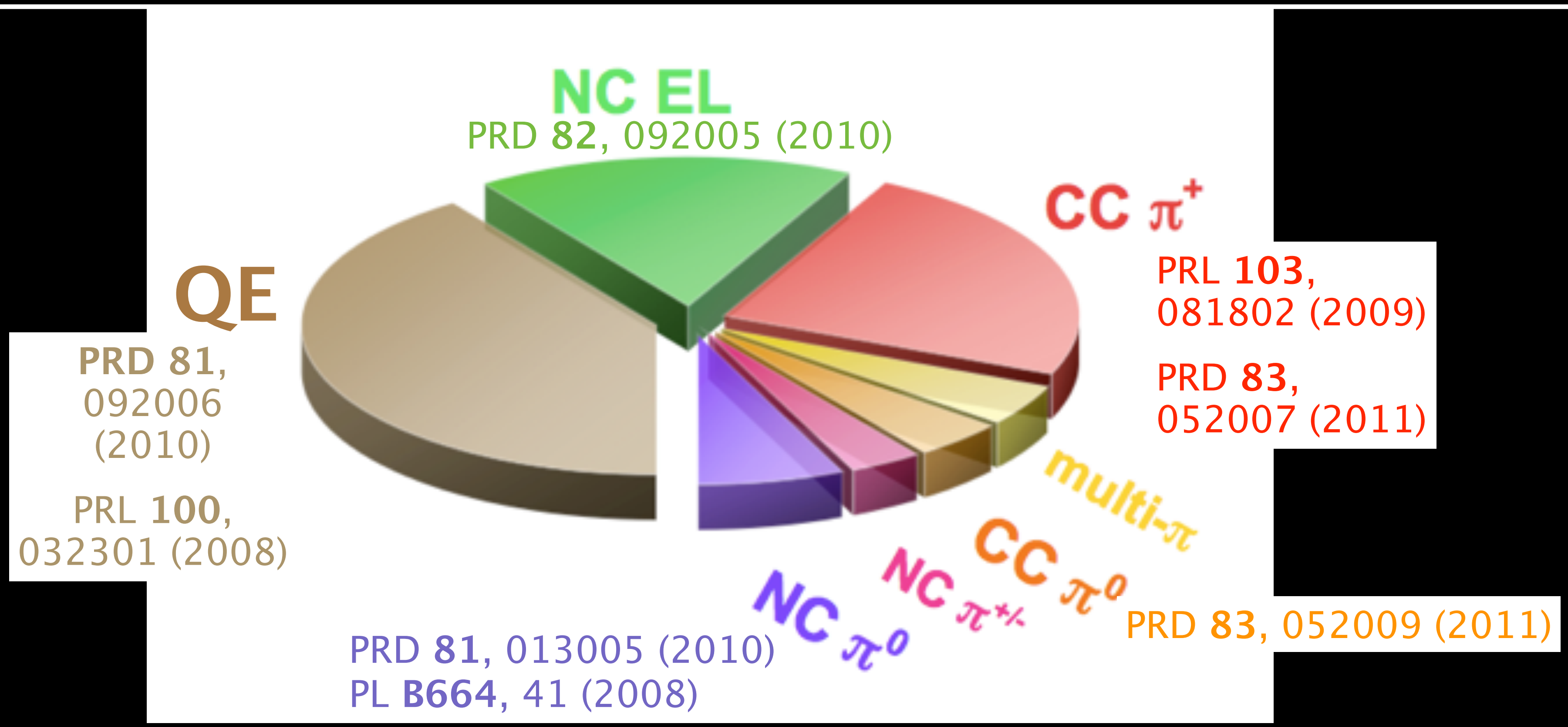
Oscillation search data from MiniBooNE





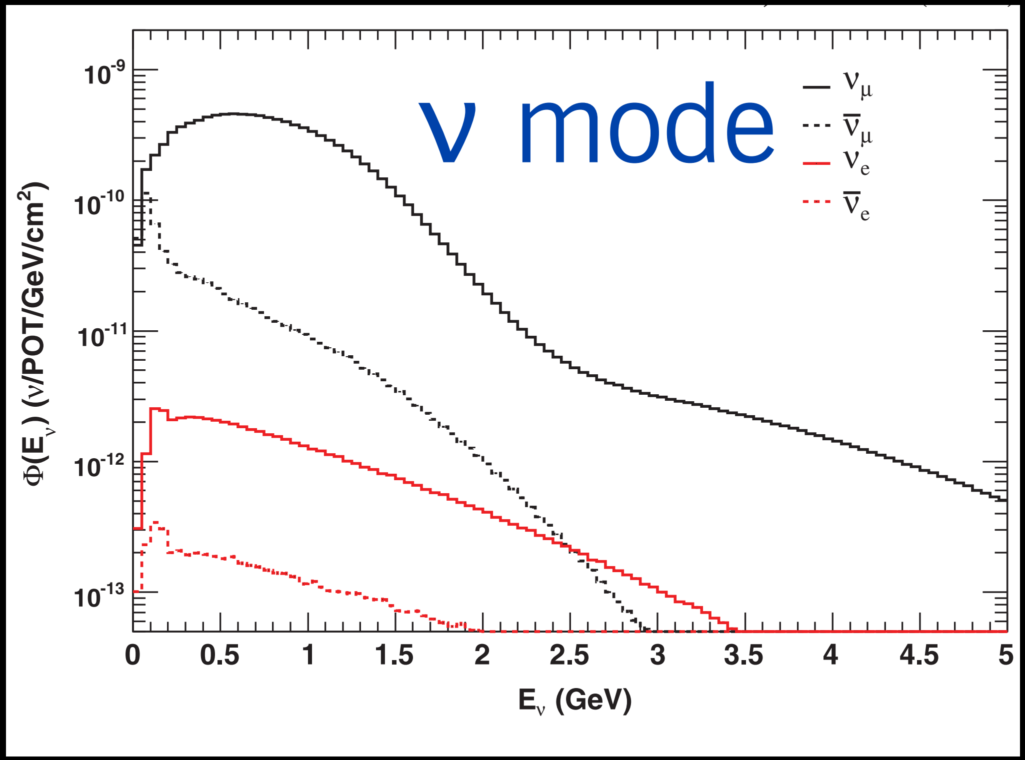
- Significant (~3.8σ) excess of $\nu_e/\bar{\nu}_e$, especially at low energies
- Oscillation interpretation: combined fit to both modes

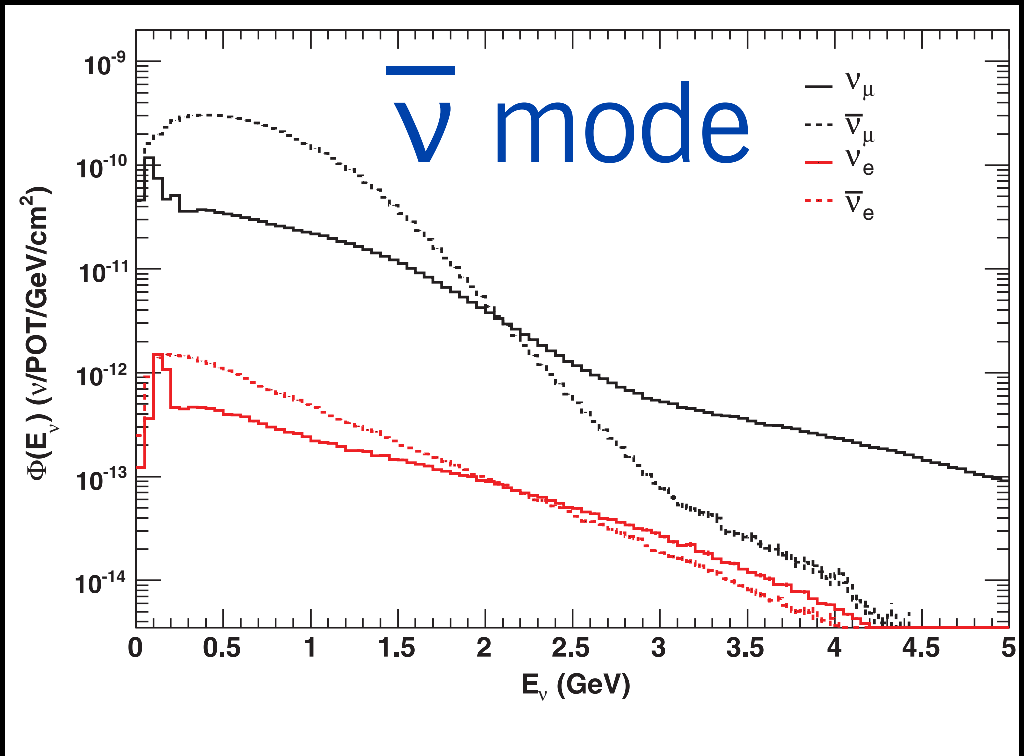
Cross-section Results from MiniBooNE



- We have measured exclusive cross-sections covering 90% of ν interactions in MB.
- Additional ν results to be reported this fall.
- These results have motivate much new and needed theoretical work on neutrino-nucleus scattering.

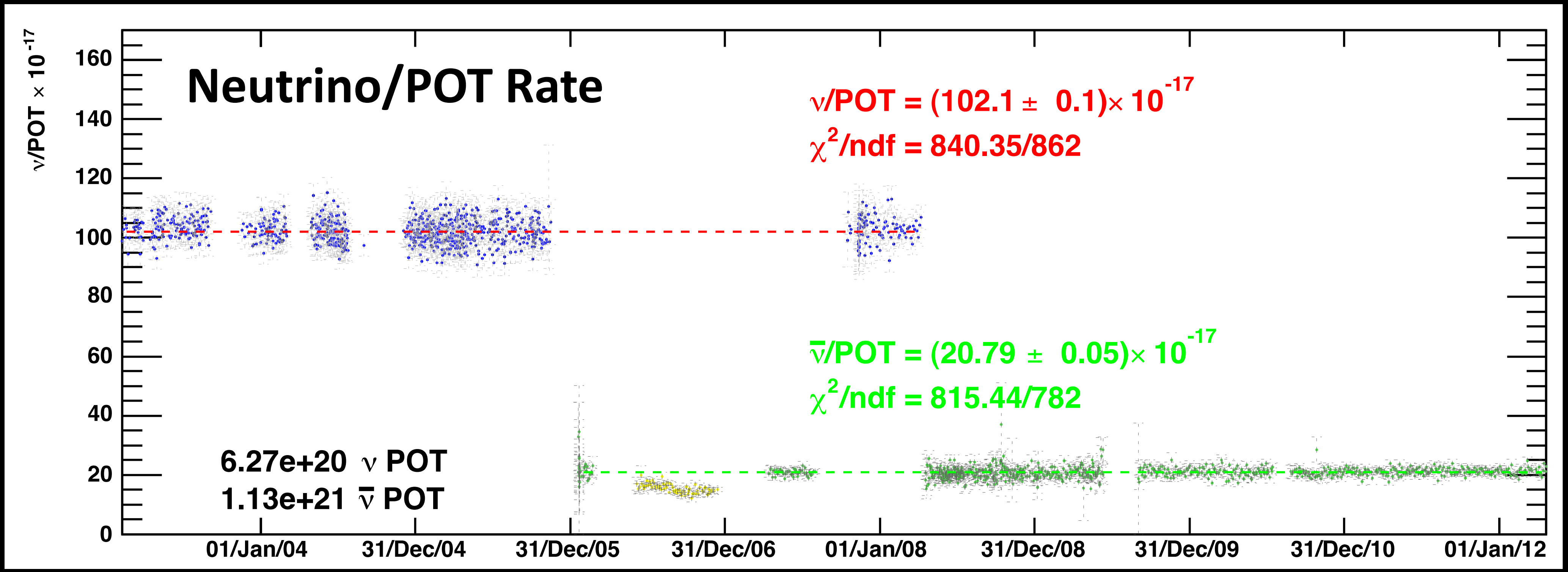
Flux Prediction





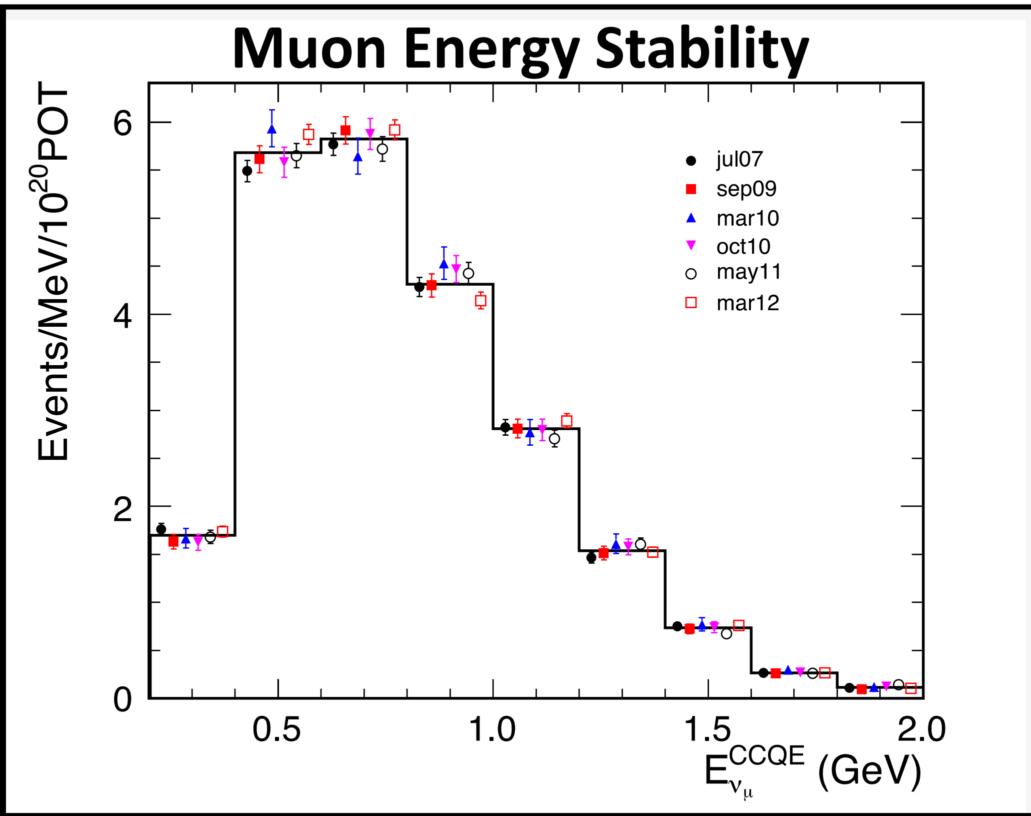
- Prediction uses Geant4 MC with external input from HARP, E910 (plus older experiments for kaons)
- Published in PRD 79, 072002 (2009)

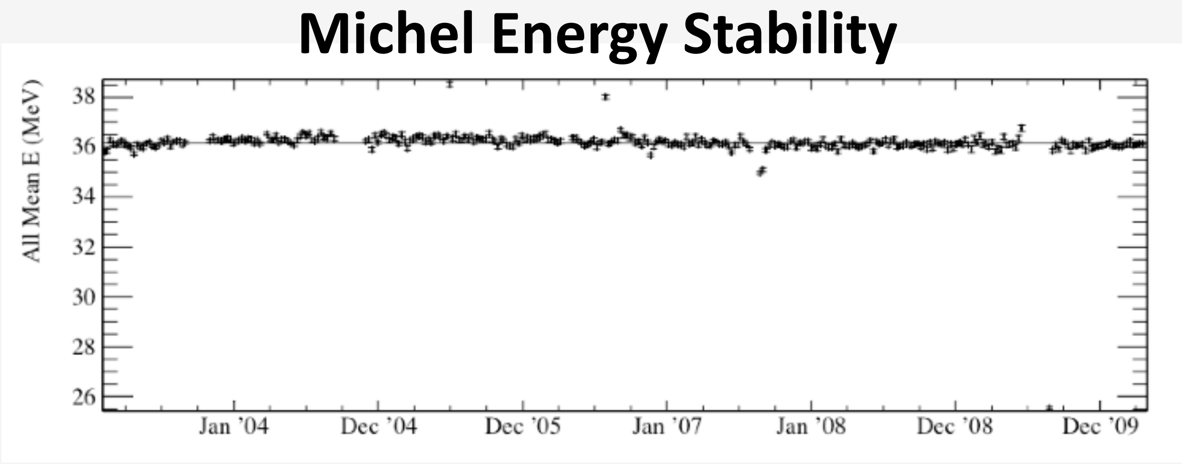
Beam stability over ten years



- Neutrino/POT rate has been very stable (<2%). Some notable issues:
  - Horn replacement in 2004, since then second horn/target has run stable with over 392 million pulses, a world record! (See Bartoszek talk)
  - Iron blocks in the 25 m absorber region fell Dec 2006, reducing antineutrino rate, before being repaired.

Detector stability over ten years





- Beam and detector data quality cuts for oscillation and cross-section analysis remove only 2-3% consistently over the lifetime of the experiment.
- During lifetime of the experiment only 35 PMT/electronic channels failed (~2%). Small detector energy shifts corrected during calibration/analysis.

Further Neutrino/Antineutrino Running: Worthwhile?

- The Booster Neutrino Beam will be used again for MicroBooNE and possibly other projects. Is it worth taking more MiniBooNE data with the current detector to increase statistics?
  - Neutrino mode: probably not. We are reaching systematic limits.
  - Antineutrino mode: possibly. We are still statistics limited, but many years would be required to double the data set.
- There are possible new configurations that would address some systematic issues.

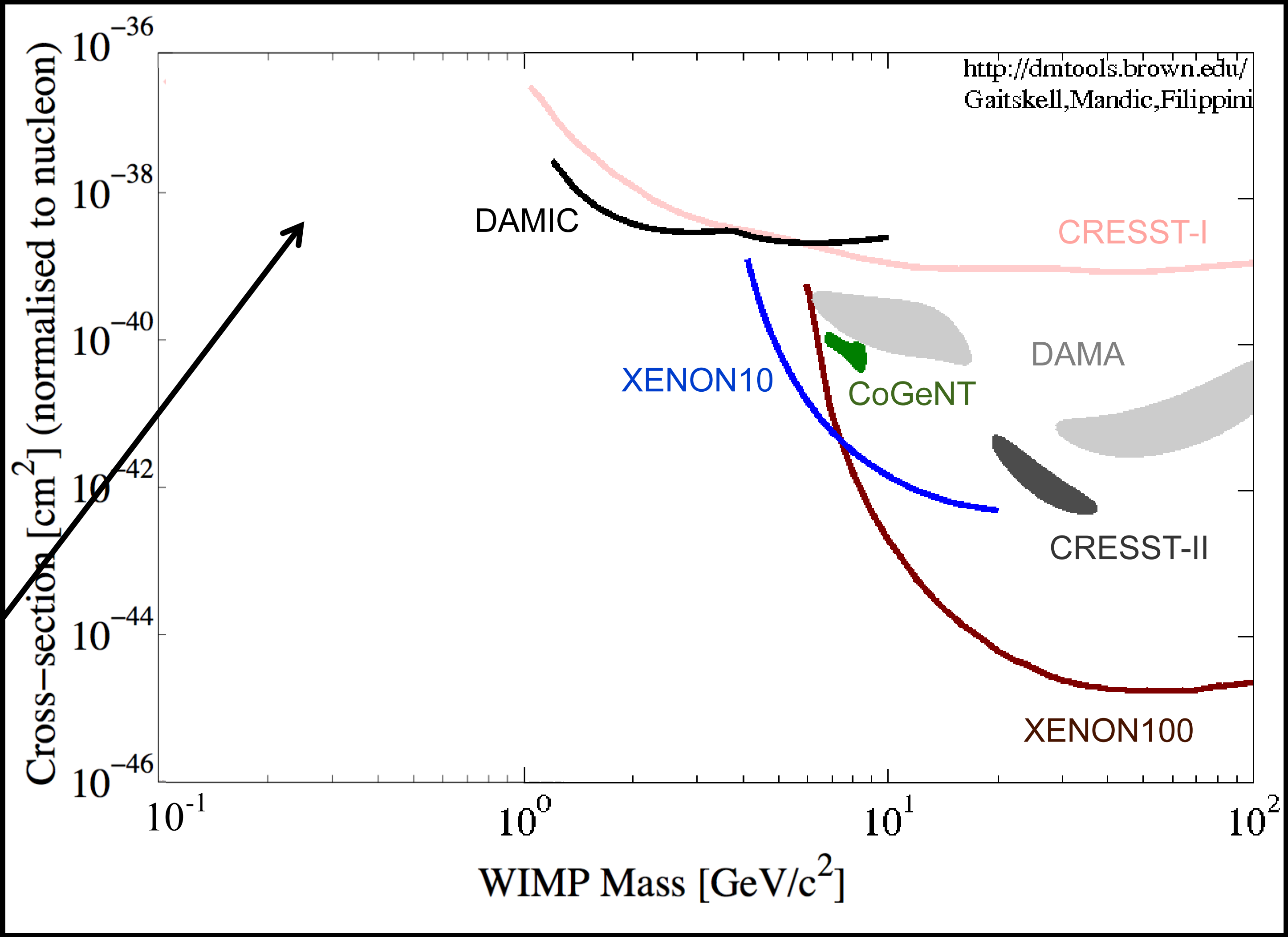
Future Possibilities for MiniBooNE

- MircoBooNE starts running on the BNB in early 2014 in neutrino mode.
- FNAL accelerator shutdown ends early 2013.
- $\sim$1 year opportunity for MB to run in whatever mode we dictate (WIMP search in beam off target mode). Proposal submitted to 2012 PAC.
- When MicroBooNE runs in neutrino mode, MB can run concurrently.
- Studying possibility of adding scintillator to separate backgrounds from oscillation signal. LOI submitted to 2012 PAC.

World Data on Low-Mass Spin-Independent WIMP Scattering

- Traditional underground direct detection experiments run out of sensitivity below ~1 GeV. It turns out MB can probe this region. See PAC proposal for theory and experiment details:

- http://www.fnal.gov/directorate/program_planning/Oct2012Public/P-1032_MiniBooNE_proposal_2012.pdf

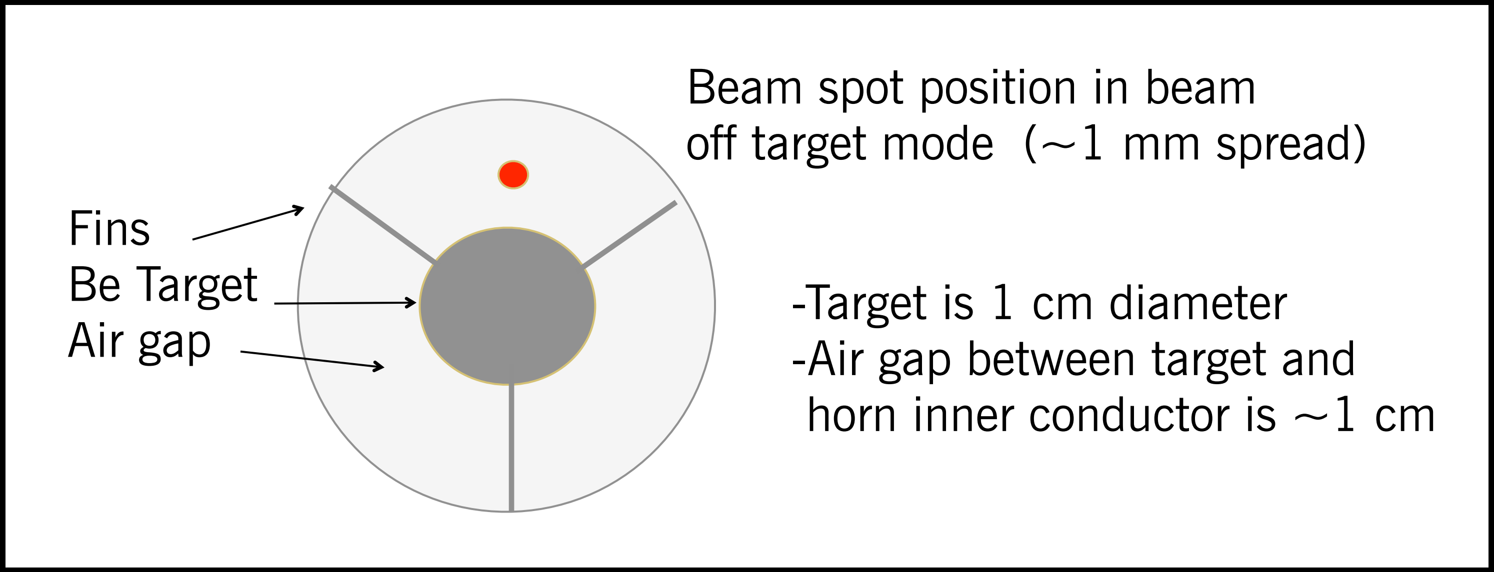


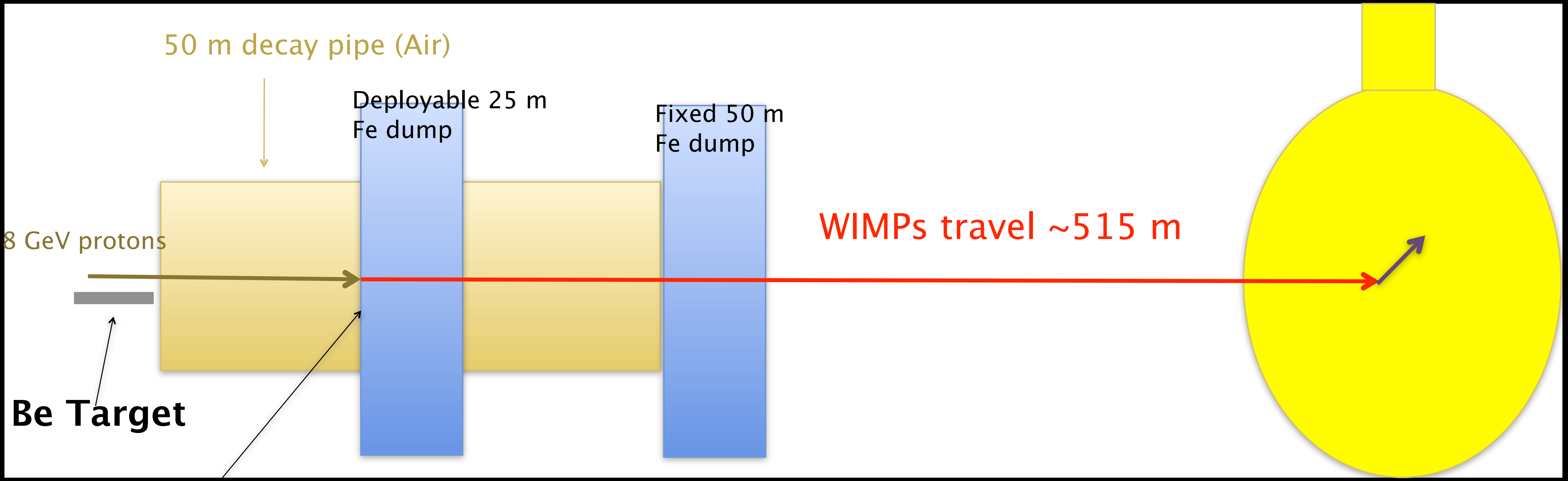
WIMP search with off-target beam

- Idea: let primary beam bypass target and horn, and strike steel beam absorber directly
- π^0 and η produced by protons in the iron quickly decay and then couple to WIMPs
- Charged mesons are absorbed in the iron before decaying, which significantly reduces the neutrino flux (backgrounds to WIMP search) by a factor of 42.
- WIMPs scatter off nucleons or electrons (to first order looks like neutrino elastic scattering).

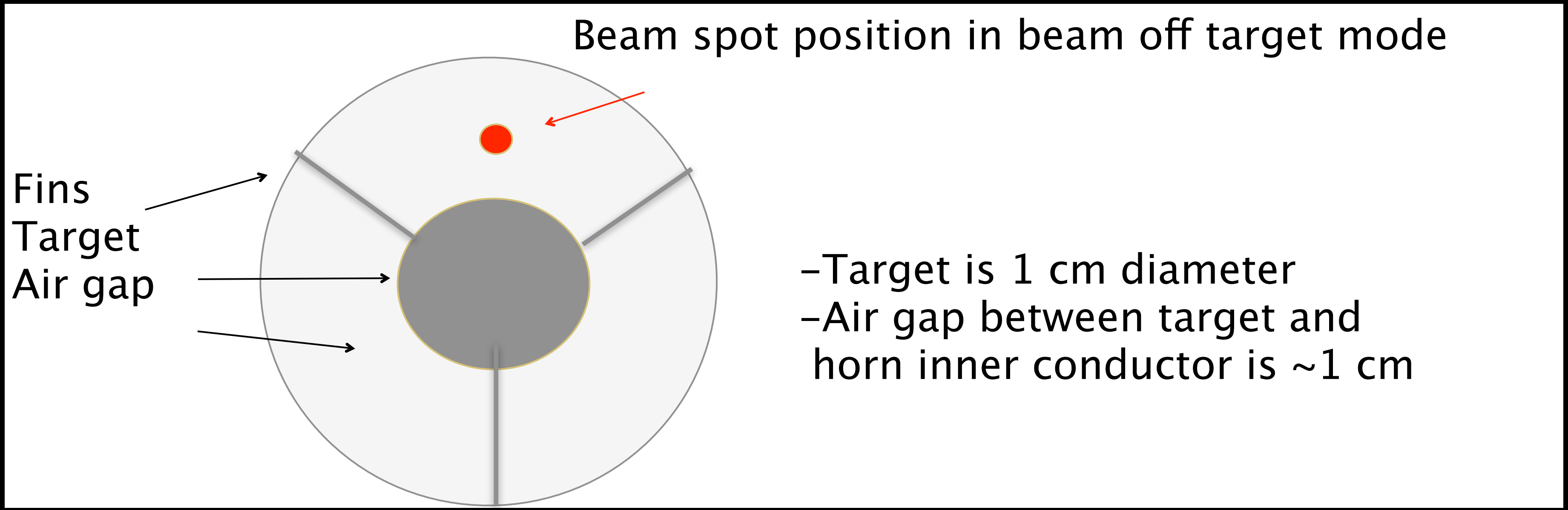
BNB Beam Off-Target configuration

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





Beam Off-Target Issues

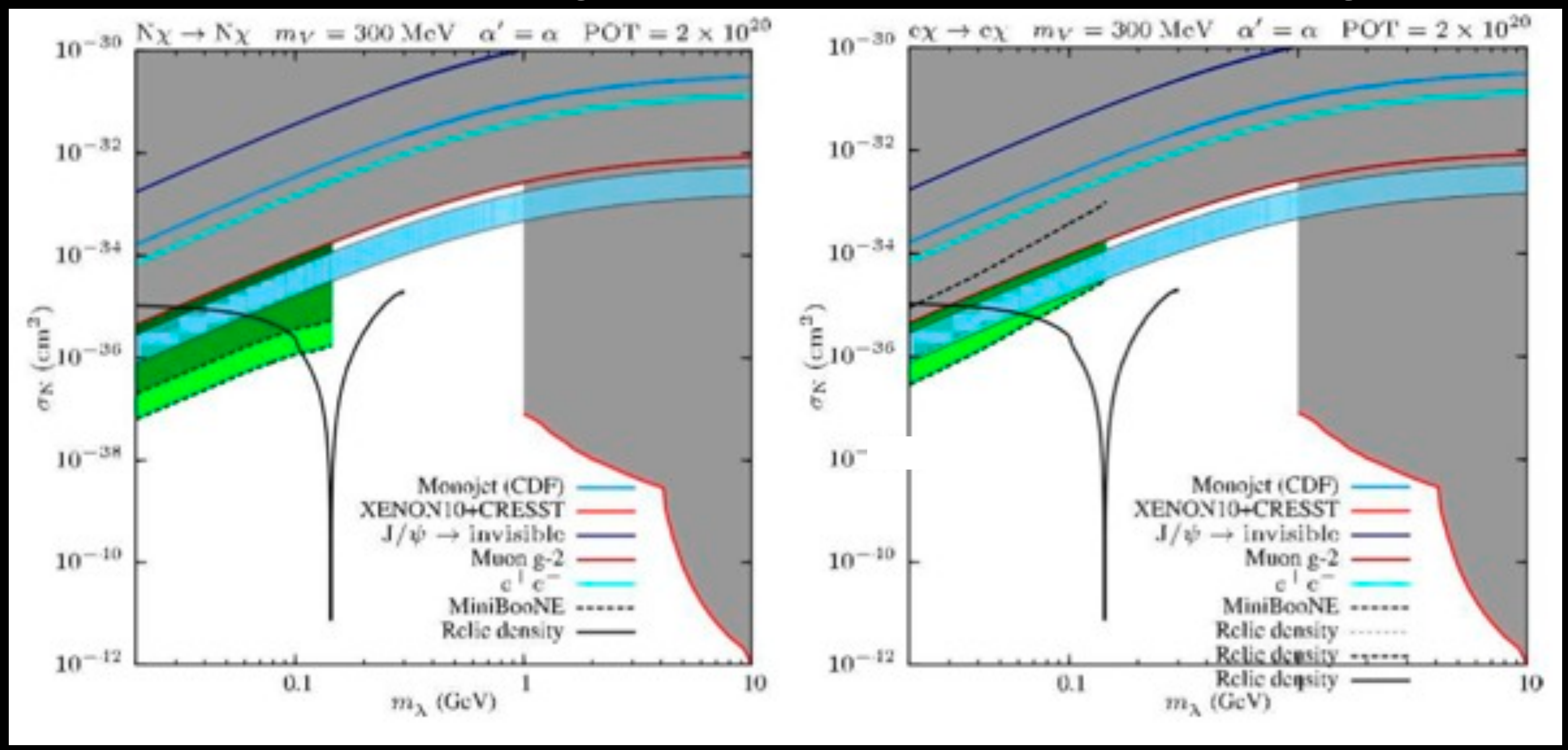


- Successfully ran beam off target on 50 m dump for 1 week in March 2012.
- Rad safety reviewed beam dump safety documents and gave approval.
- Autotune can keep beam off target with ~1mm spread.
- No radiation alarms or beamline monitoring anomalies.
- No risk to the horn from spray, as “donut collimator”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

MiniBooNE WIMP Sensitivities

WIMP-Nucleon Scattering   WIMP-Electron Scattering

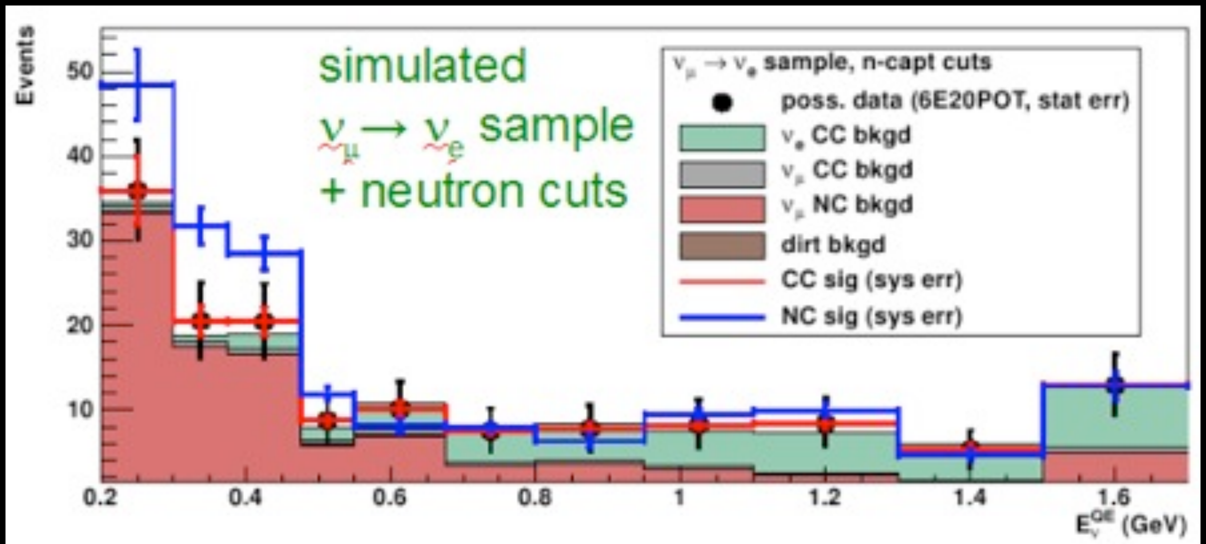
WIMP cross section
vs
WIMP mass

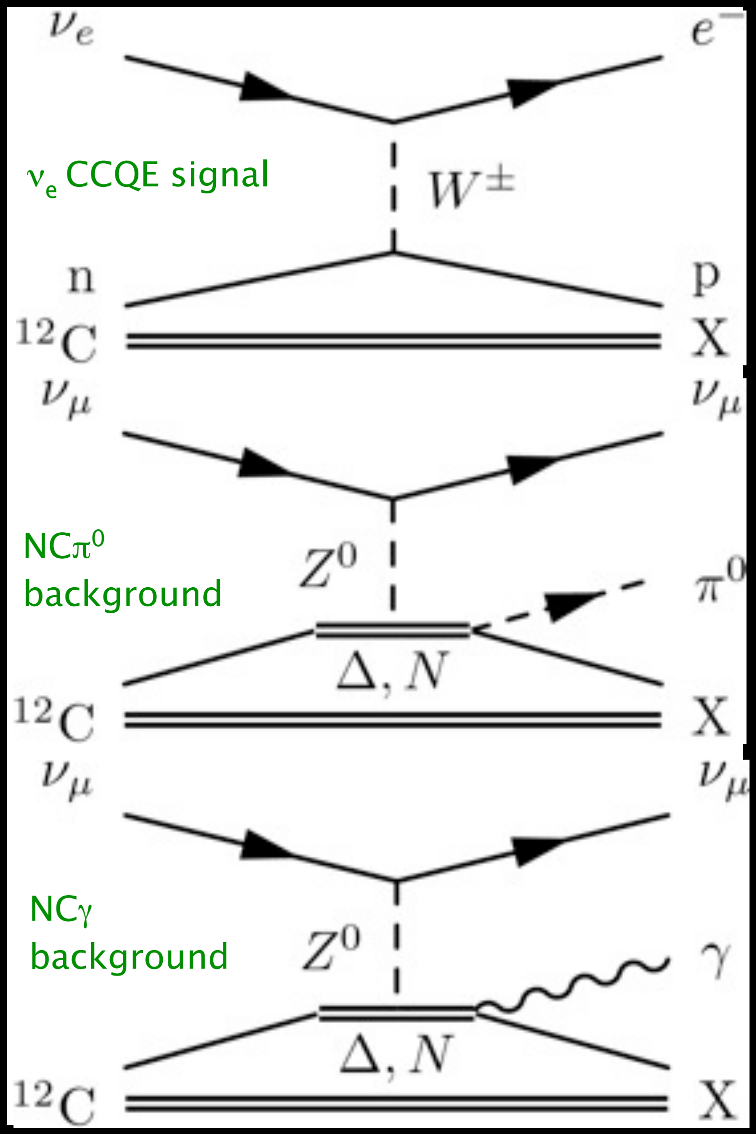


- WIMPs scatter off nucleons or electrons (to first order looks like neutrino elastic scattering).
- Number of WIMP events detected in MiniBooNE:
  - Dark Green: >1000
  - Green: 10-1000
  - Light Green: 1-10 → After all cuts, can achieve close to this region
- Light blue band is muon g-2 signal in Vector portal WIMP model.
- Solid black line is where WIMP relic density matches observation

MiniBooNE Scintillator Option

- Test NC backgrounds: Add scintillator to enable detection of 2.2 MeV n-capture photons for an enhanced $\nu_\mu \rightarrow \nu_e$ search at low energy.
  - CC oscillation signal events have very few neutrons: 1% (at 200MeV) → 10% (1 GeV)
  - NC backgrounds have ~50% neutrons
  - can measure these neutron fractions with $\nu\mu$ events
- Plan: add scintillator, redo oscillation search with 6E20POT and n-capture analysis
- Will reduce systematic erorrs on NC backgrounds

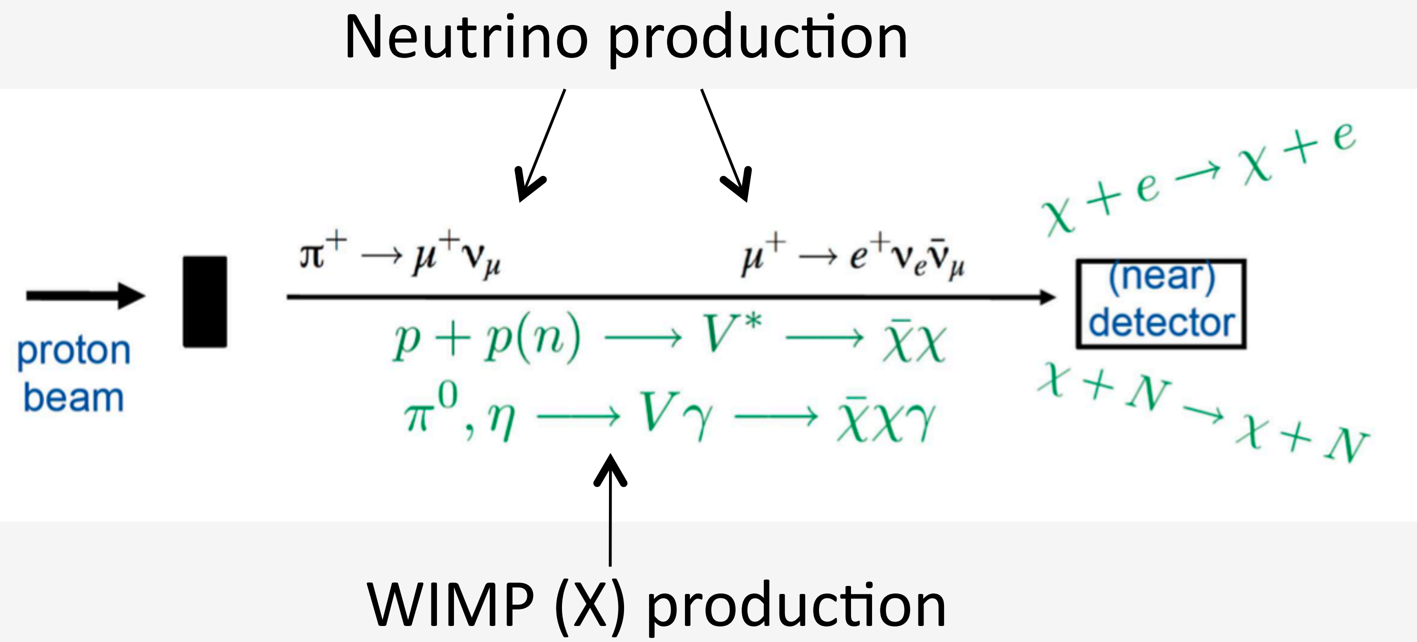


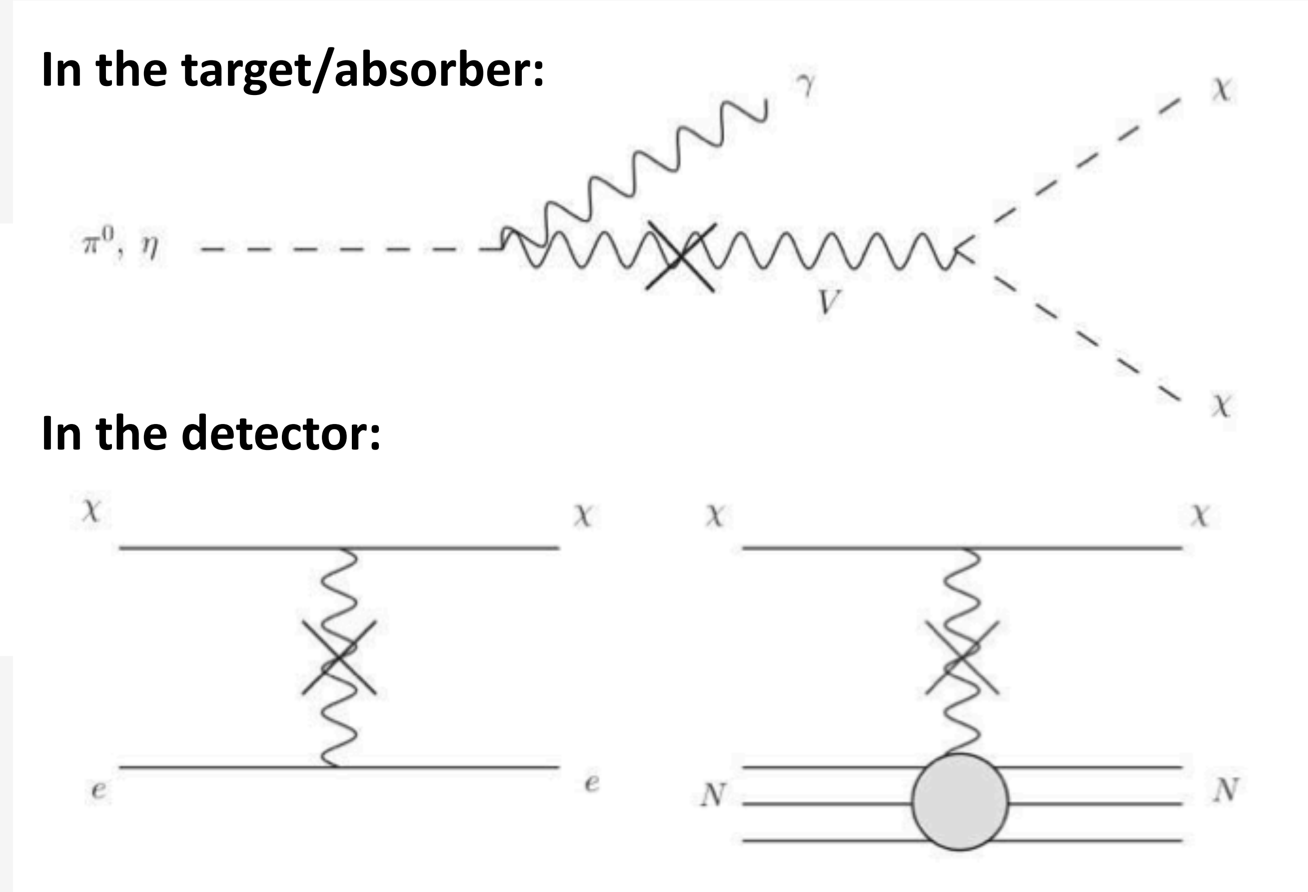


Summary

- Booster Neutrino Beam has run (mostly) stably for a decade! Flux delivery goals have been achieved for both neutrinos and antineutrinos.
- Both ν_e and $\bar{\nu}_e$ appearance searches reveal significant low-energy excesses
- Further running proposed:
  - New scintillator run to reduce background systematics.
  - WIMP search in beam off target mode.

Producing a Dark Matter Beam





Electron Elastic scattering

Nucleon Elastic scattering

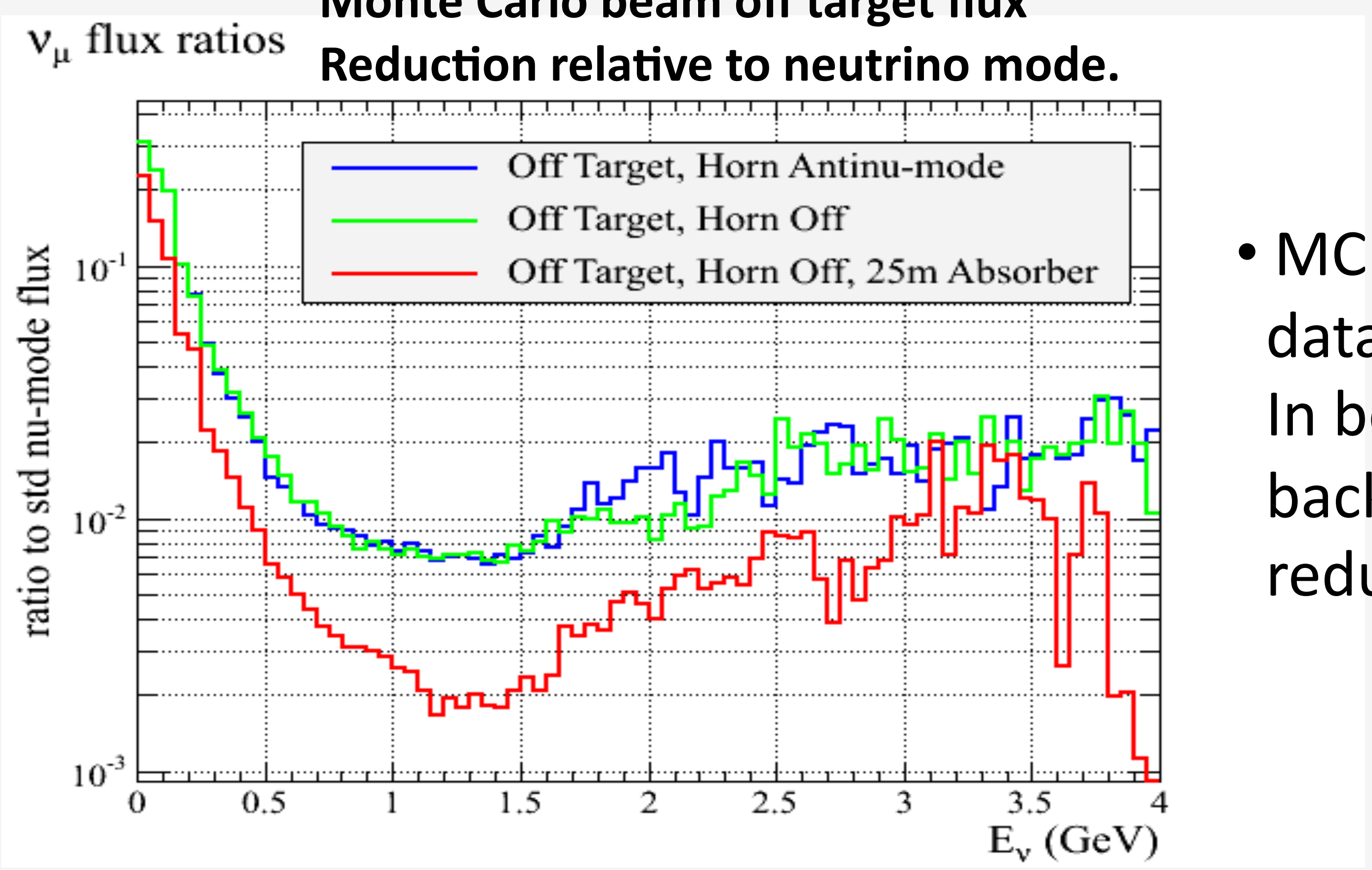
- A dark matter Vector (V) portal model (minimal U(1) extension of the SM) is required for low mass WIMPs production, which couples to photons in π^0 and η decays.
- Monte Carlo Simulation of WIMP Production at MiniBooNE:
  - Use HARP-MiniBooNE Be target Sanford-Wang meson production model.
  - Use MiniBooNE determined acceptance, fiducial, and energy cuts (35% efficiency).
  - Calculate regions of M_x, M_v, κ, α’ parameter space probed for 1, 10, and 1000 events.

Neutrino Rate (background to WIMP searches) 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

Monte Carlo beam off target flux Reduction relative to neutrino mode.

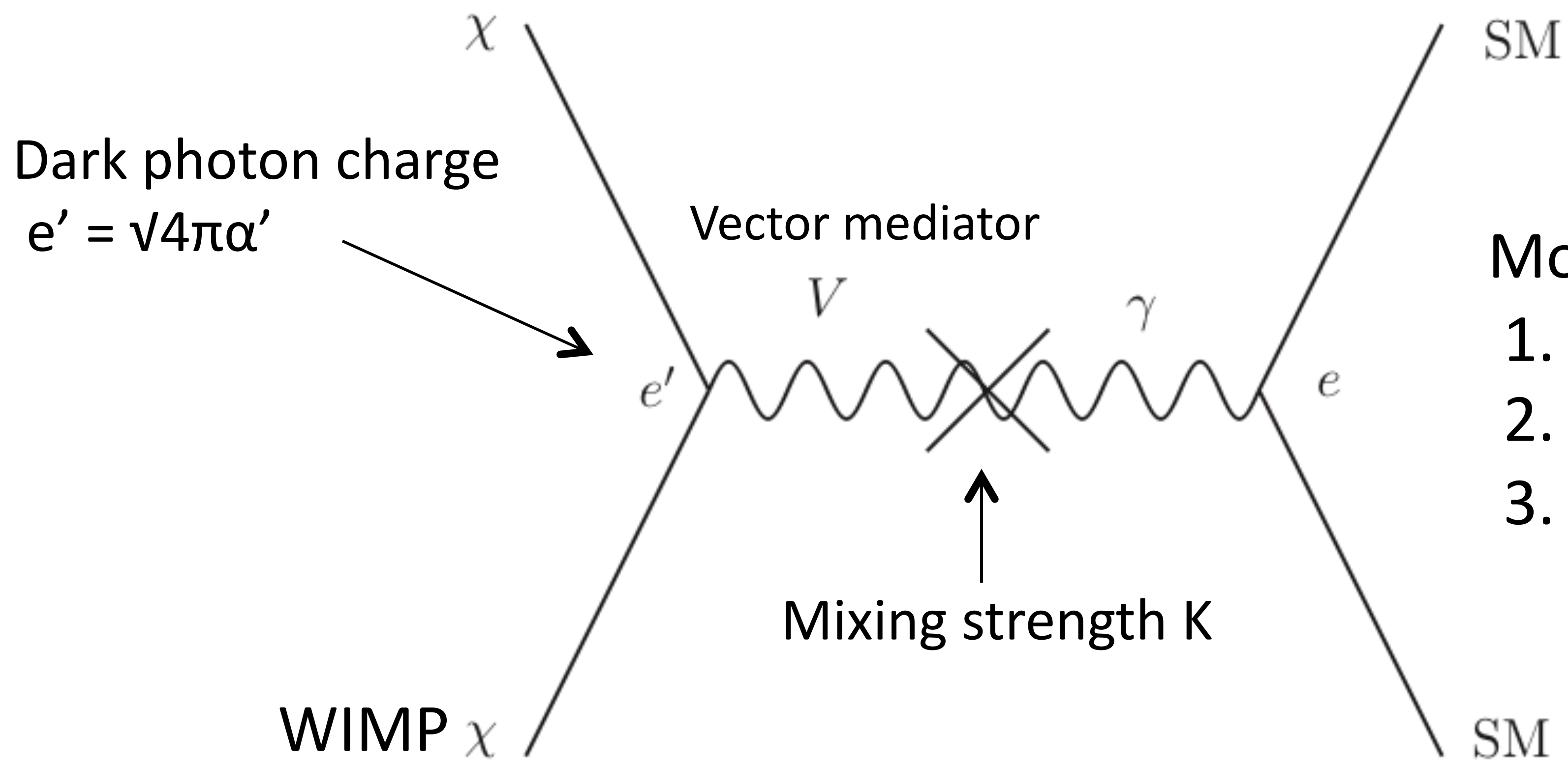


- MC prediction and measured data flux reduction are consistent. In beam off target mode neutrino backgrounds to WIMP searches are reduced by a factor of 42!

Minimal Dark Matter Vector Portal Model

Required for Low Mass WIMPs to achieve correct thermal relic abundance

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



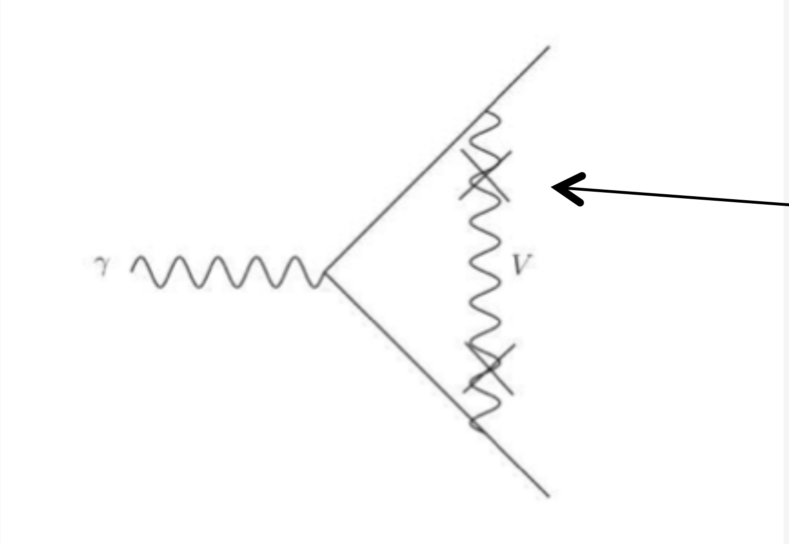
Model assumptions:

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.

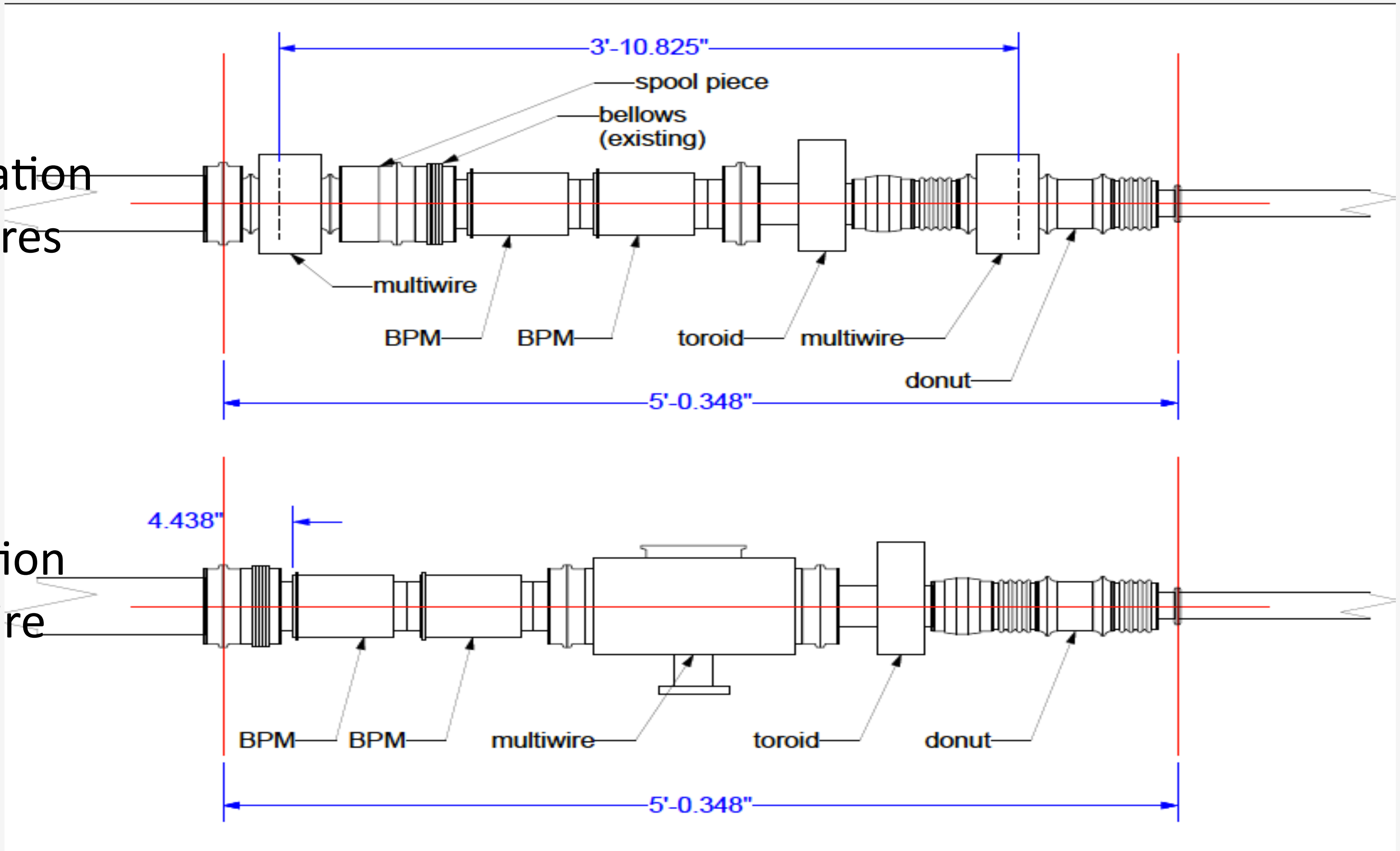


The crosses represent the kinetic mixing κ of the vector V with the photon

Upgrades to Beam Positioning

NEW configuration with 2 multiwires

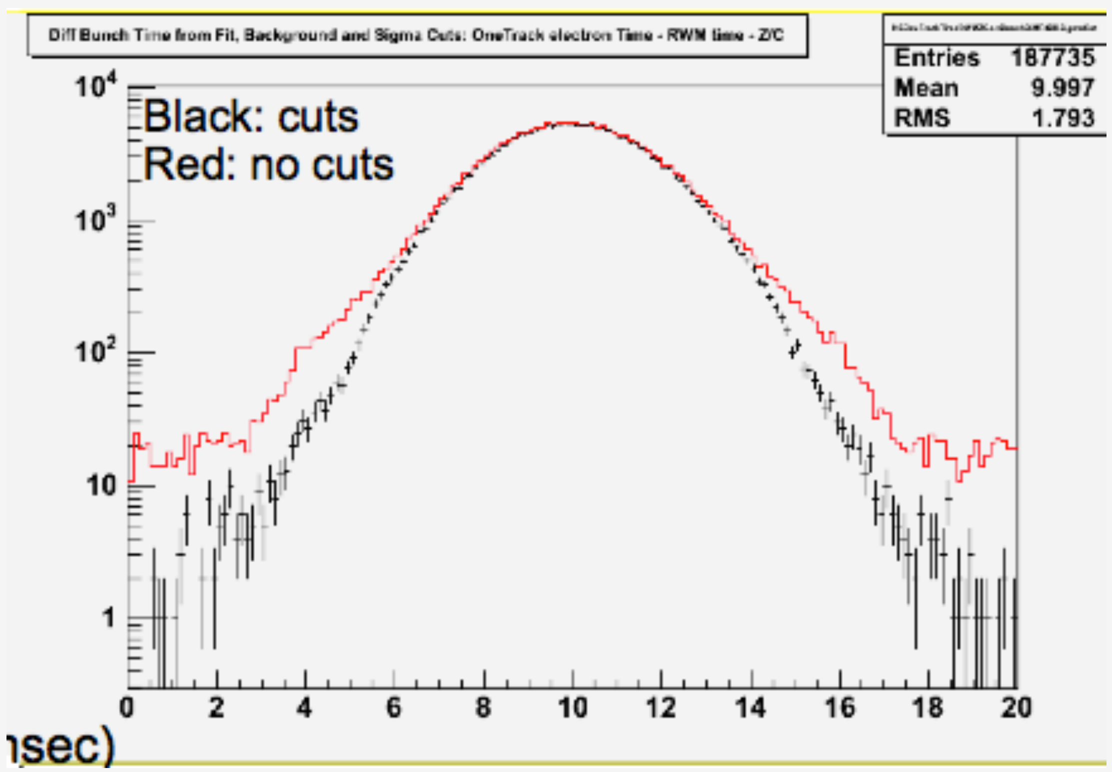
Old configuration with 1 multiwire



- With new dual low mass multiwires, will be able to reliably point the proton beam at the detector to within 0.5 mrad.

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.