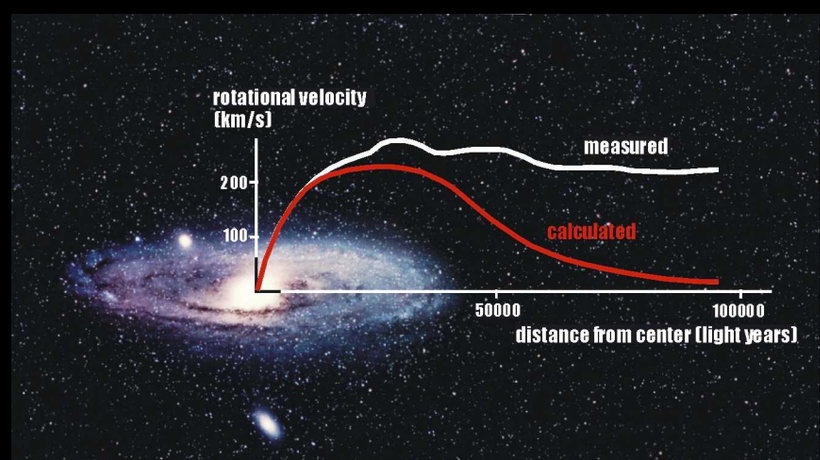
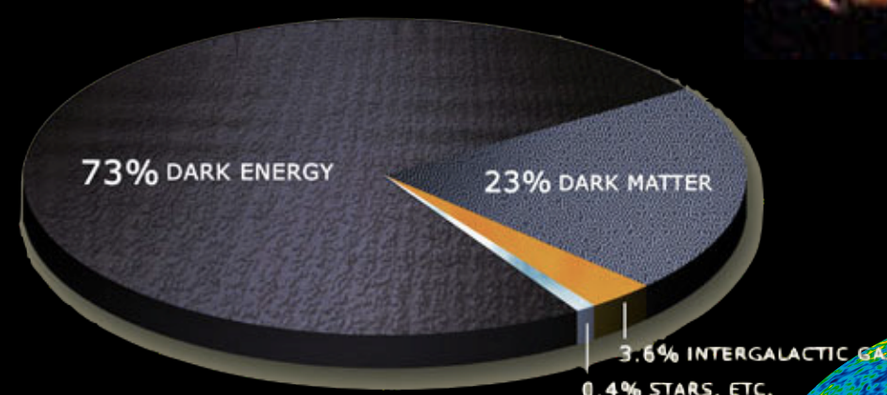
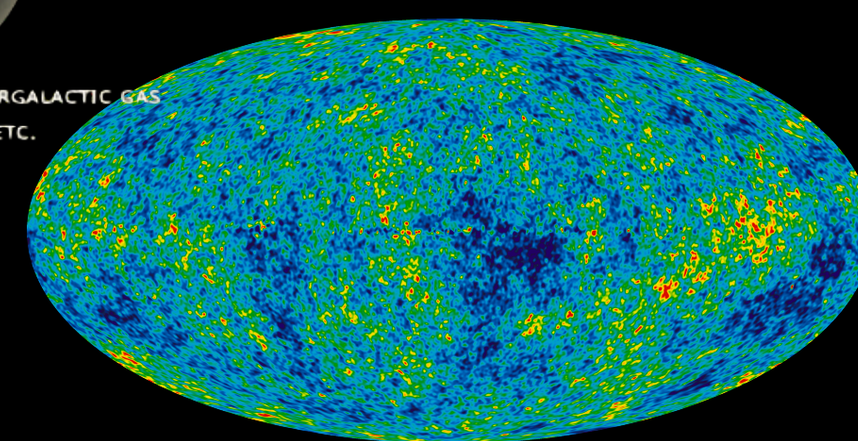
Dark Matter Search at MiniBooNE

Ranjan Dharmapalan
Argonne National Laboratory
Fermilab Users Meeting 2016

Dark Matter

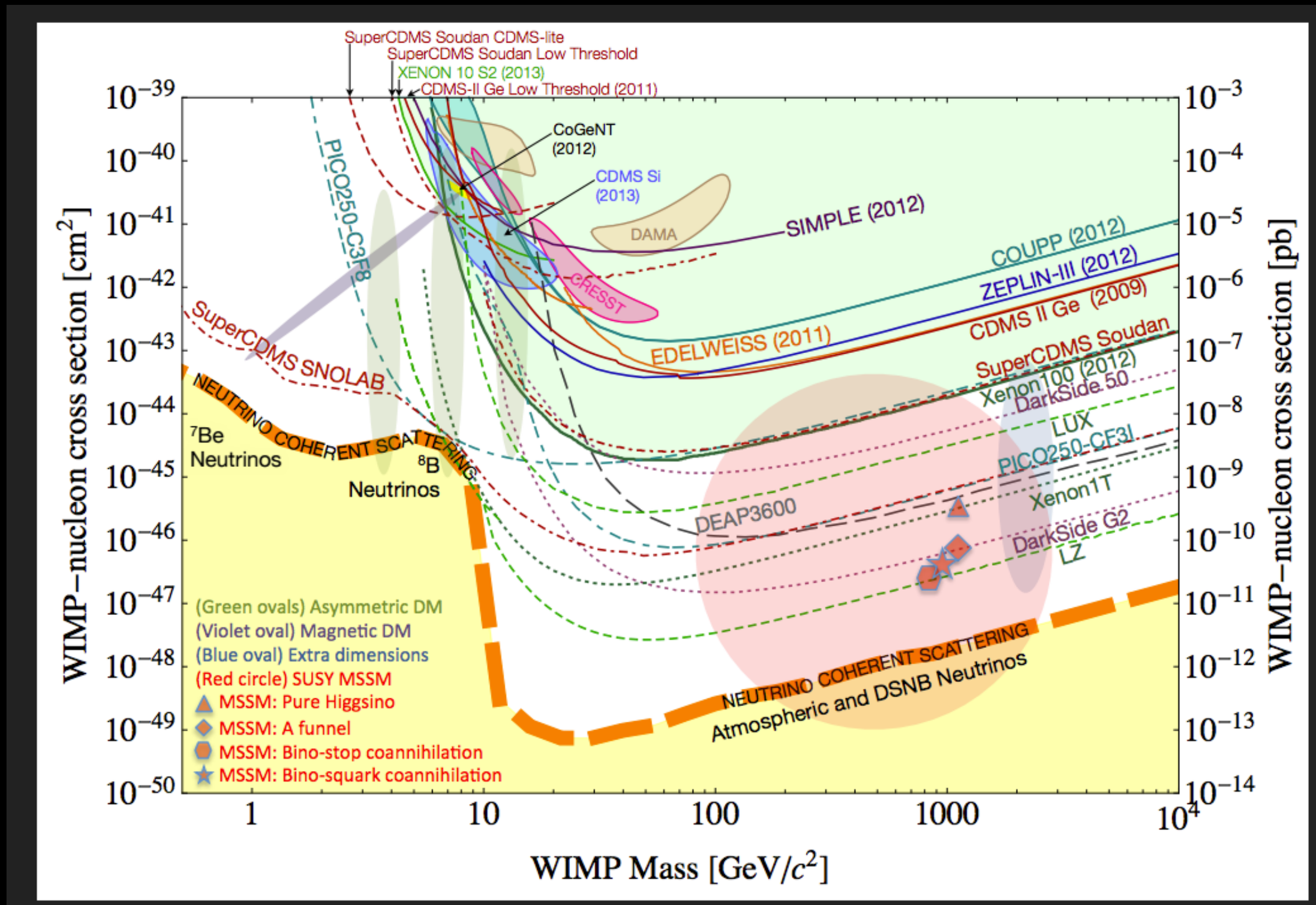






- One of the few empirical hints of new physics

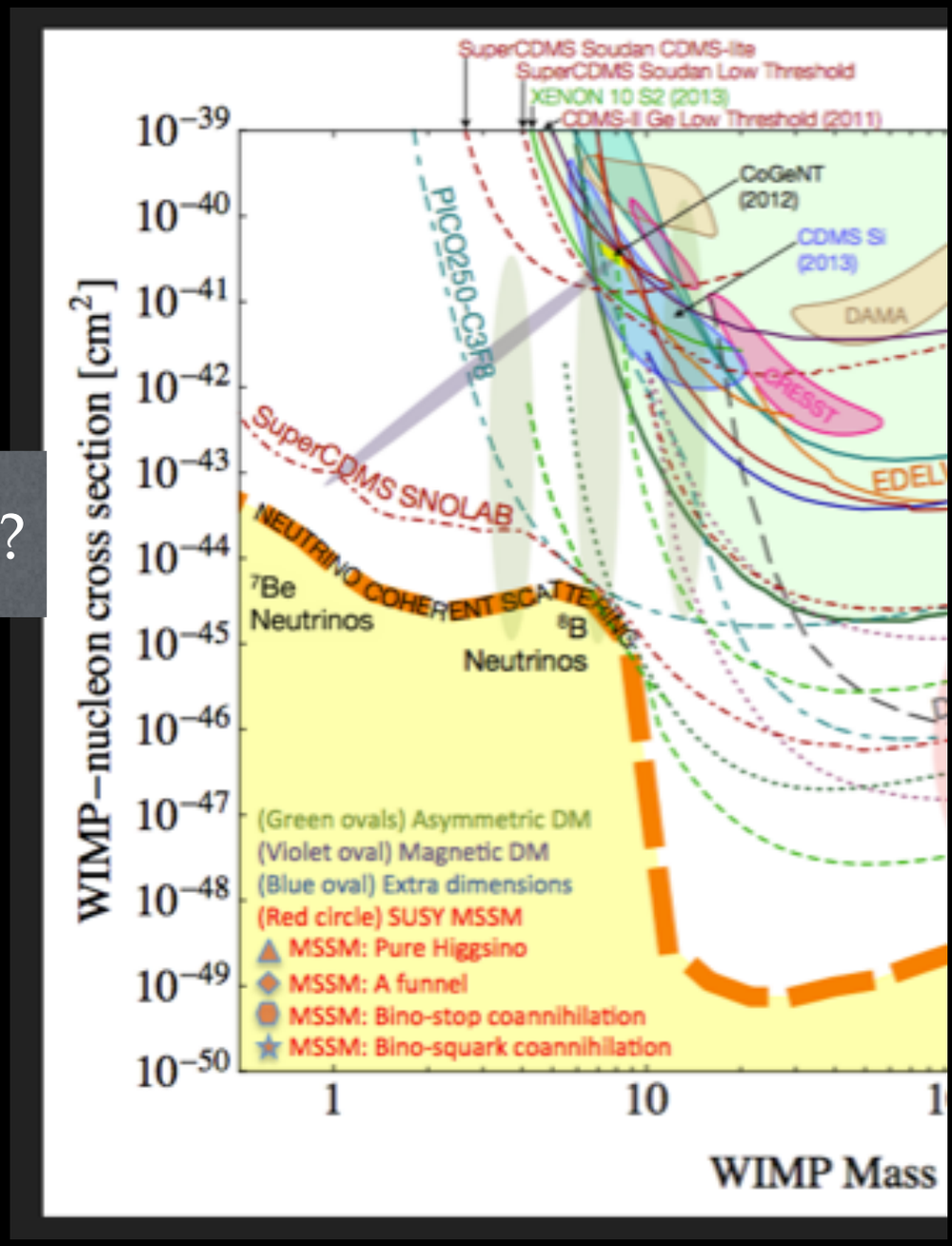
Where is it ?


SuperCDMS Soudan CDMS-lite
SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
Xenon1T
DarkSide G2
LZ
DEAP3600
EDELWEISS (2011)
CRESST
PICO250-C3F8
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
NEUTRINO COHERENT SCATTERING
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm²]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c²]

Light Dark Matter

Theory: See Gordon Krnjaic's talk!
(Dark Sector)
Vector Portal
Higgs Portal
Neutrino Portal

What about here?



Experiment:

- Nuclear recoil too weak
- Need relativistic dark matter

MiniBooNE Collaboration (Experimentalists)

+

The Theory Collaboration

B. Batell
University of Chicago, Chicago, IL, 60637

P. deNiverville, M. Pospelov, & A. Ritz
University of Victoria, Victoria, BC, V8P 5C2

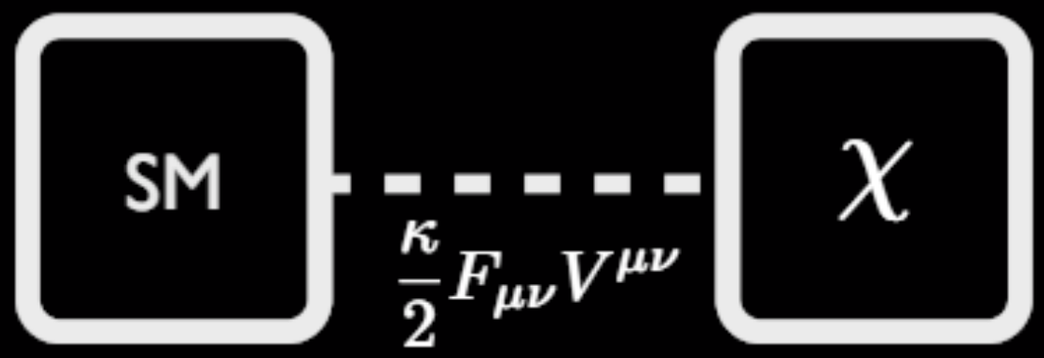
D. McKeen
University of Washington, Seattle, WA, 98195

=

Search for Accelerator Production of Dark Matter with MiniBooNE

A.A. Aguilar-Arevalo,[1] M. Backfish,[2] A. Bashyal,[3] B. Batell,[4] B.C. Brown,[2] R. Carr,[5] A. Chatterjee,[3] R.L. Cooper,[6,7] P. deNiverville,[8] R. Dharmapalan,[9] Z. Djurcic,[10] R. Ford,[2] F.G. Garcia,[2] G.T. Garvey,[11] J. Grange,[12,10] J.A. Green,[11] W. Huelsnitz,[11] I.L. de Icaza Astiz,[1] G. Karagiorgi,[5] T. Katori,[13] T. Kobilarcik,[2] W. Ketchum,[11] Q. Liu,[11] W.C. Louis,[11] W. Marsh,[2] C.D. Moore,[2] G.B. Mills,[11] J. Mirabal,[11] P. Nienaber,[14] Z. Pavlovic,[11] D. Perevalov,[2] H. Ray,[12] B.P. Roe,[15] M.H. Shaevitz,[5] S. Shahsavarani,[3] I. Stancu,[9] R. Tayloe,[6] C. Taylor,[11] R.T. Thornton,[6] R. Van de Water,[11] W. Wester,[2] D.H. White,[11] and J. Yu[3]
(MiniBooNE Dark Matter Collaboration)

Benchmark model

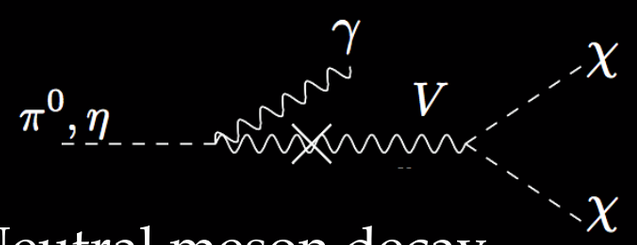


[Holdom]
[Pospelov, Ritz, Voloshin,
[Hooper, Zurek]
[Arkani-Hamed, et al]
... and many others

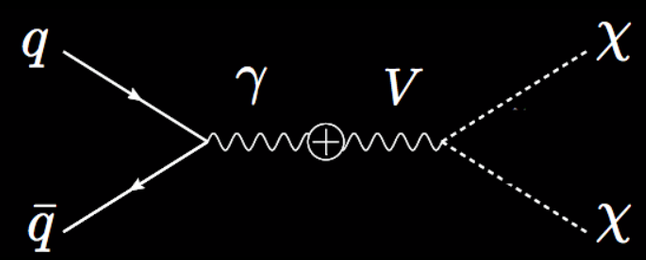
- Dark photon mediates interaction between DM and SM
- Four new parameters:
  1. m_χ : dark matter mass
  2. m_V : new vector mass
  3. $\varkappa$: coupling between DS and SM
  4. α' : new electromagnetic coupling

Benchmark model

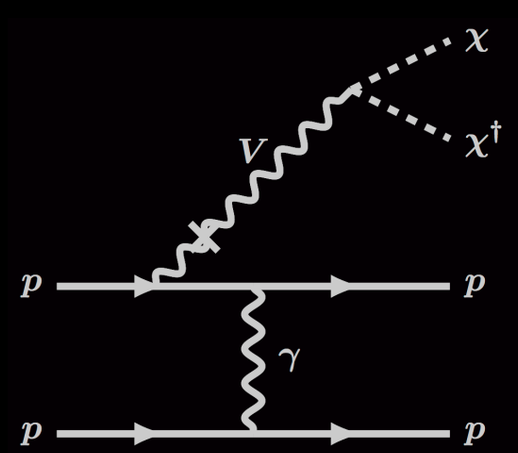
Production



Neutral meson decay

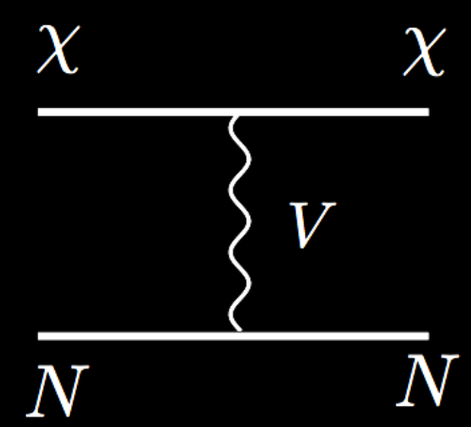


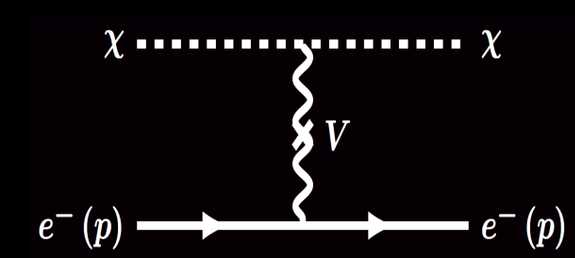
Direct production (q-q′)

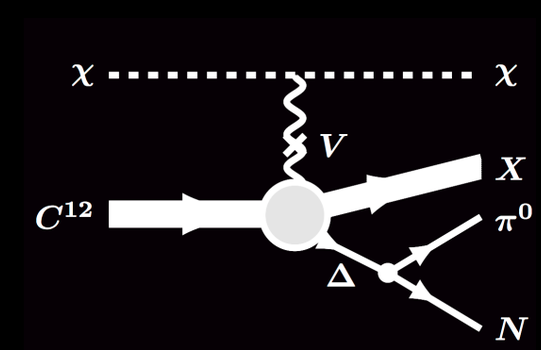


Proton bremsstrahlung

Detection



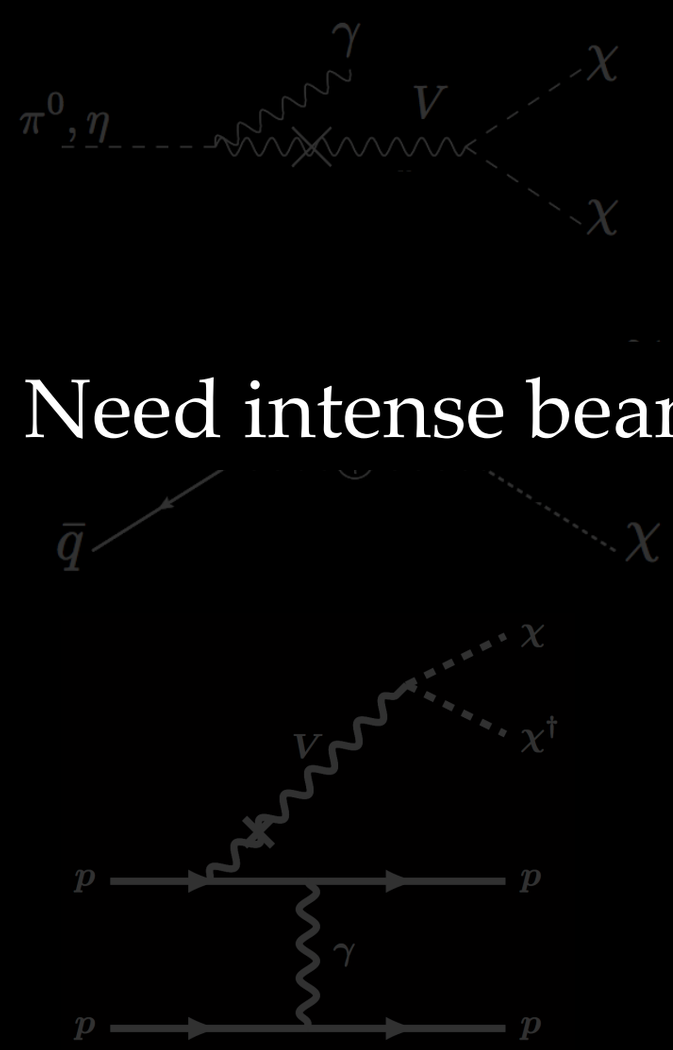




Elastic scattering off N, e, or delta resonance

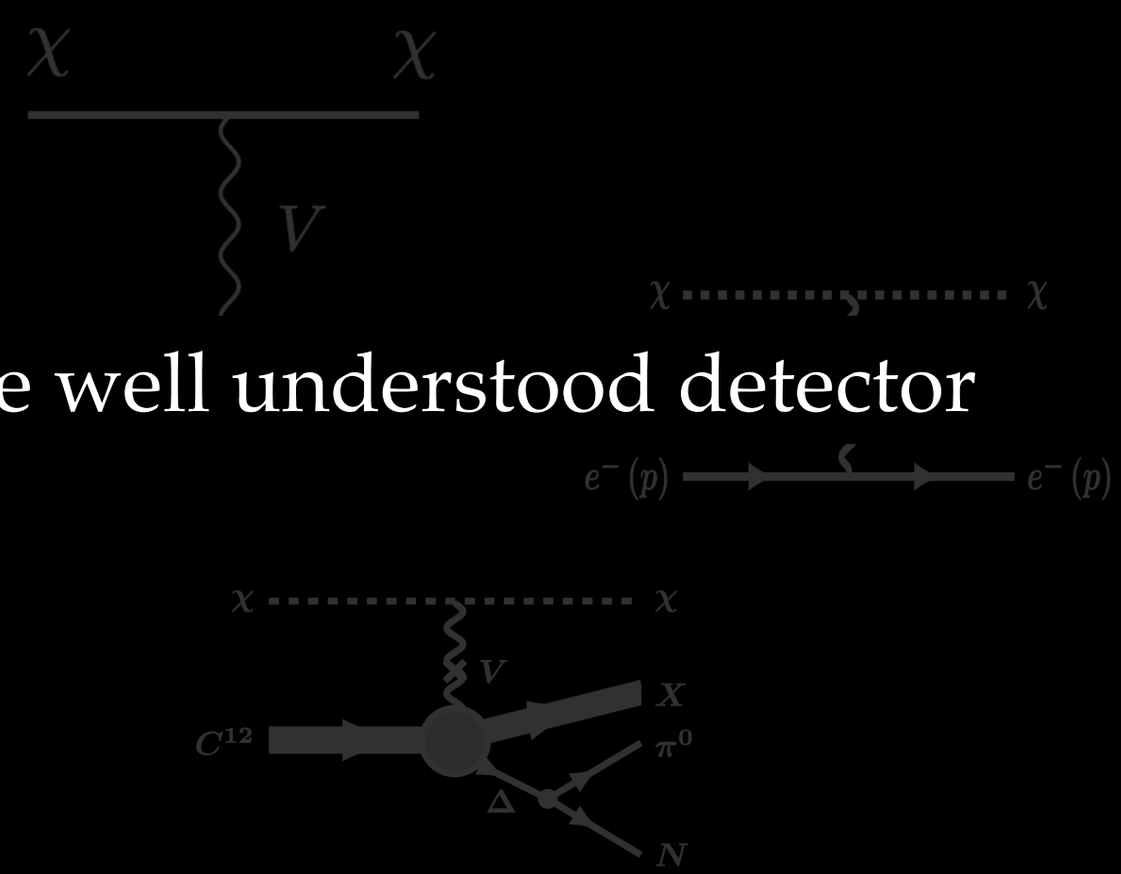
Benchmark model

Production



- Neutral meson decay,
- direct production,
- proton bremsstrahlung

Detection



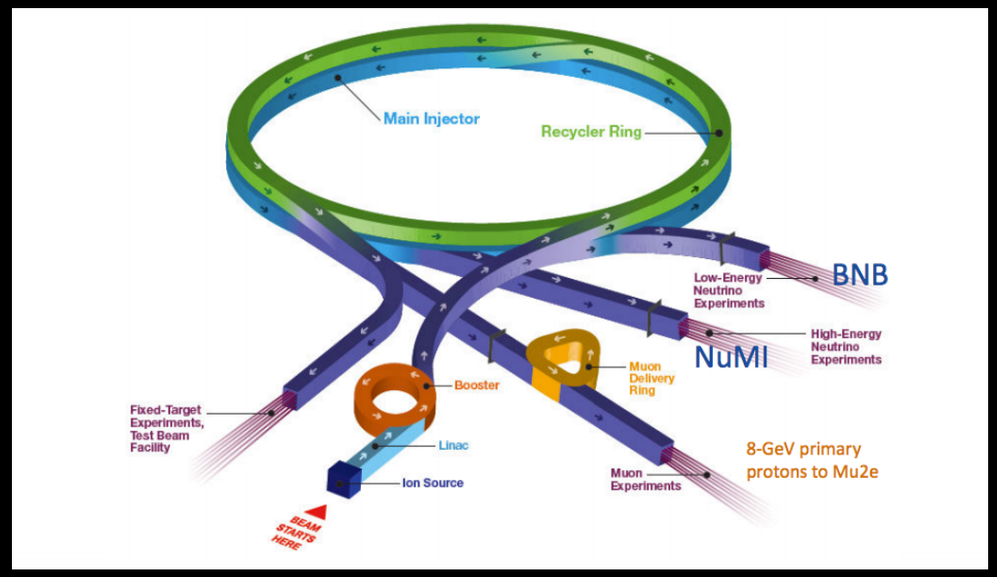
- Elastic scattering off N, e, or delta resonance

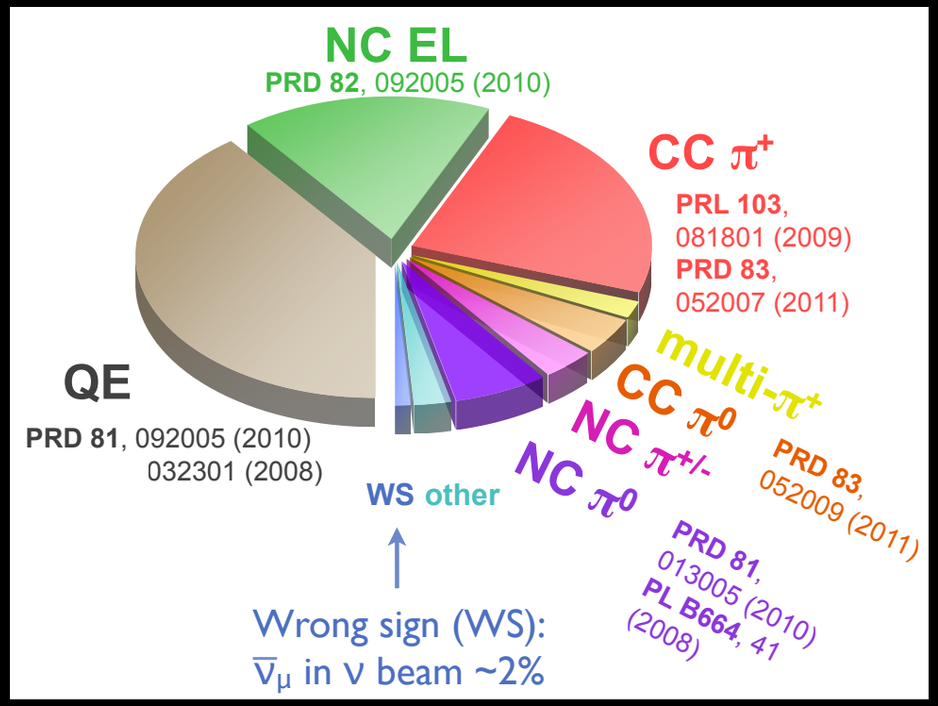
Need intense beams and a large well understood detector

MiniBooNE at Fermilab

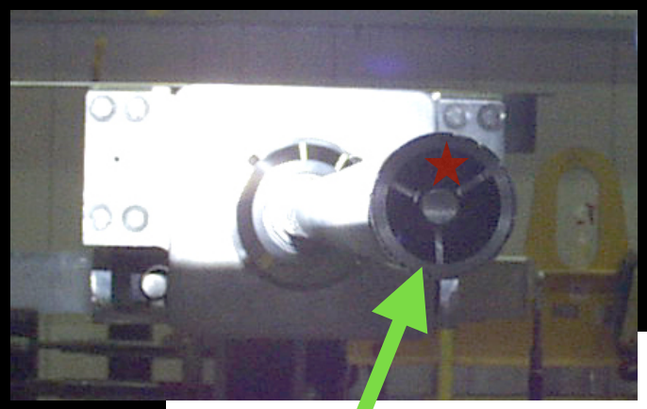
- Neutrino mode: 6.5E20 POT.
- Antineutrino mode: 11.3E20 POT.
- Recent Beam-Dump mode: 1.86E20 POT.
- 11 oscillation papers.
- 14 cross section and flux papers.
- 1 detector and 1 supernova search paper.
- 18 PhD theses.
- Over 3964 citations.
- The experiment is well understood!

NIM A599 (2009)

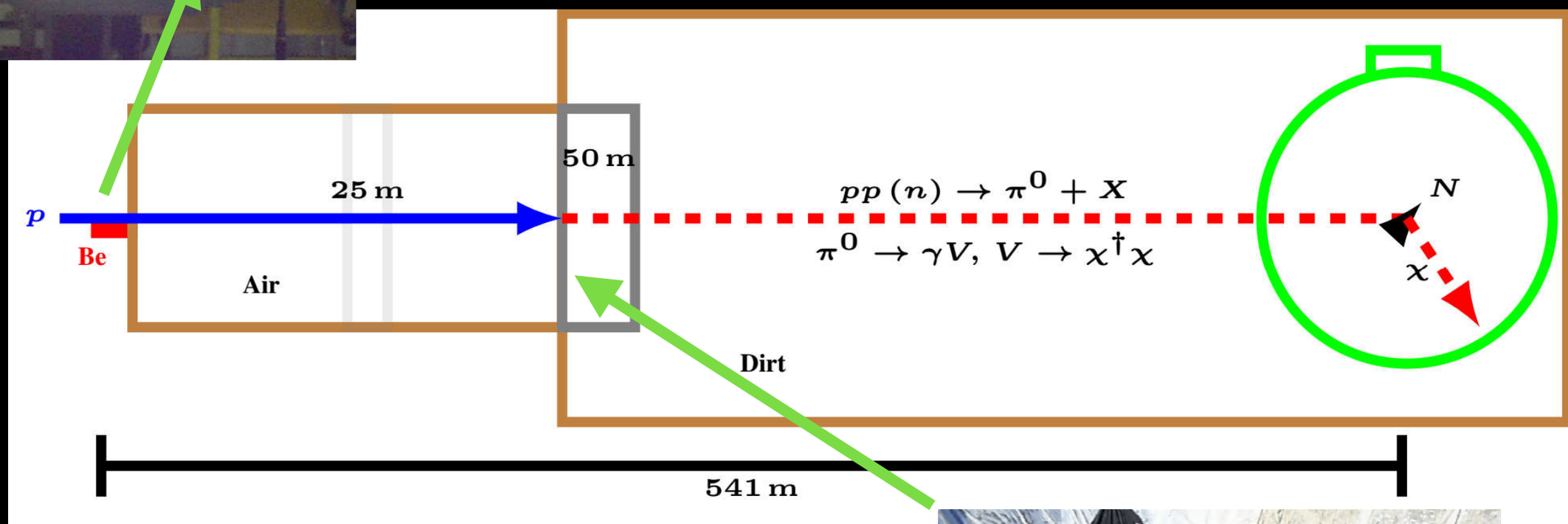




MiniBooNE: Dark Matter Mode



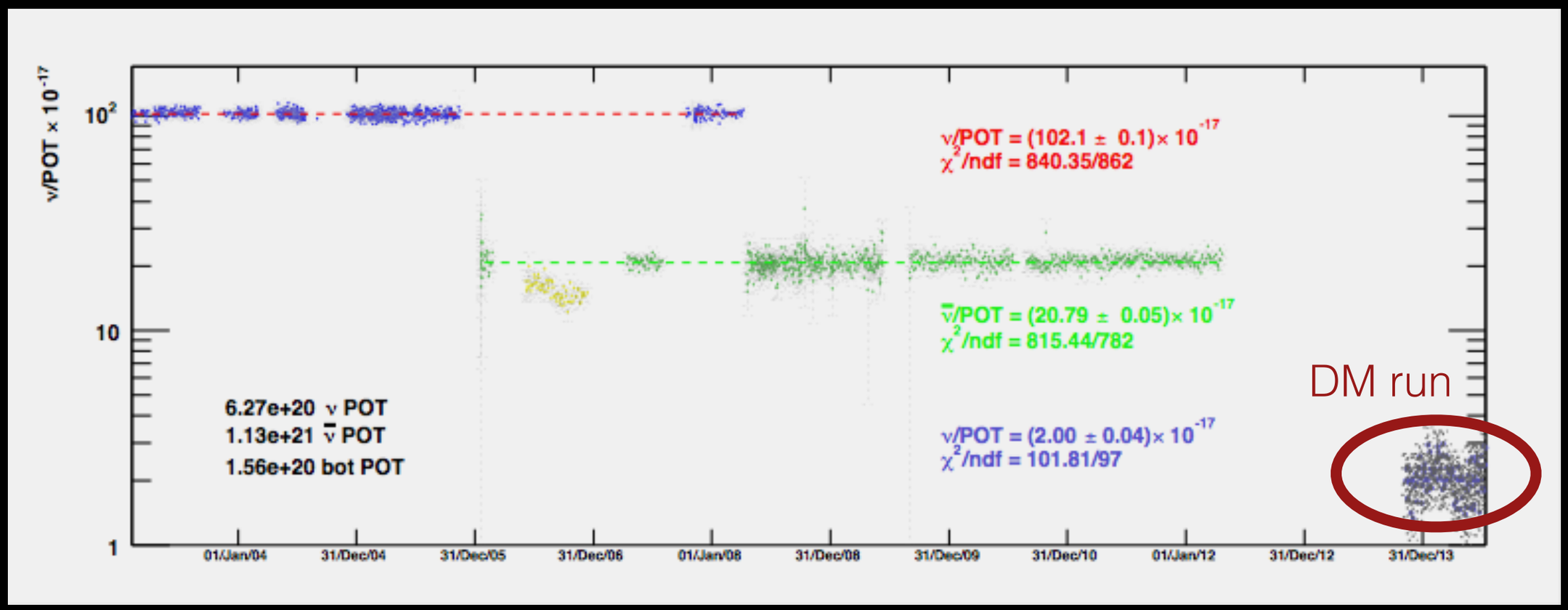
- Beam off-target to reduce neutrino background
- Neutrinos from proton-air interaction before the dump



- Charged mesons absorbed, neutral mesons decay to photons

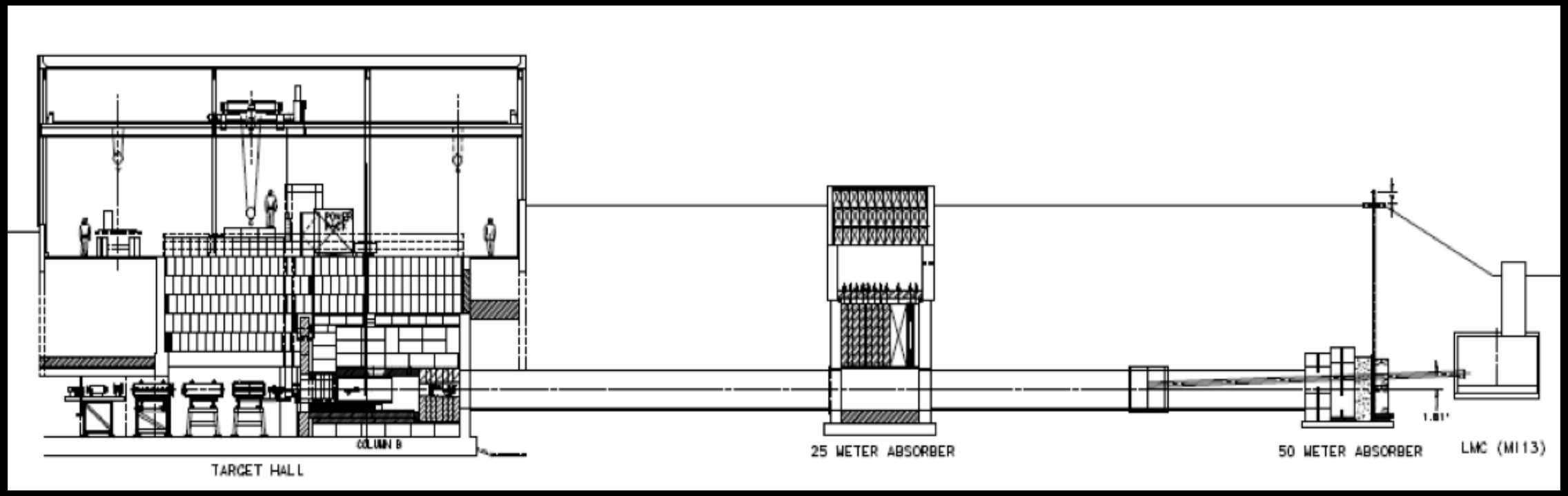
MiniBooNE: Dark Matter Mode

- In 2014 MB ran for 8 months in Dark matter mode
- 1.86E20 POT collected
  - neutrino flux suppressed by factor of ~27
  - neutrino rates " " " " ~48



MiniBooNE: Dark Matter Mode

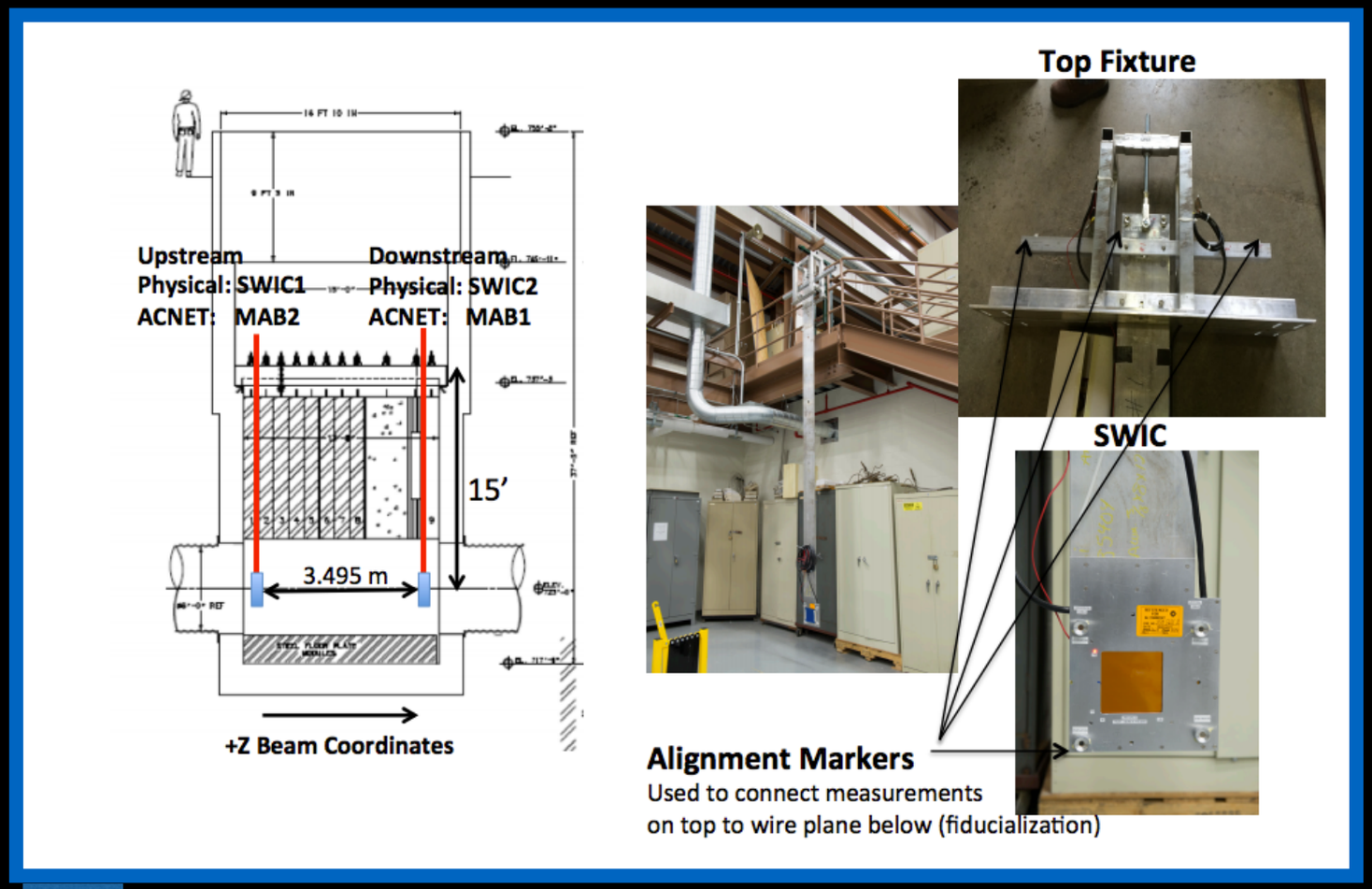
- Understanding the beam-off-target configuration

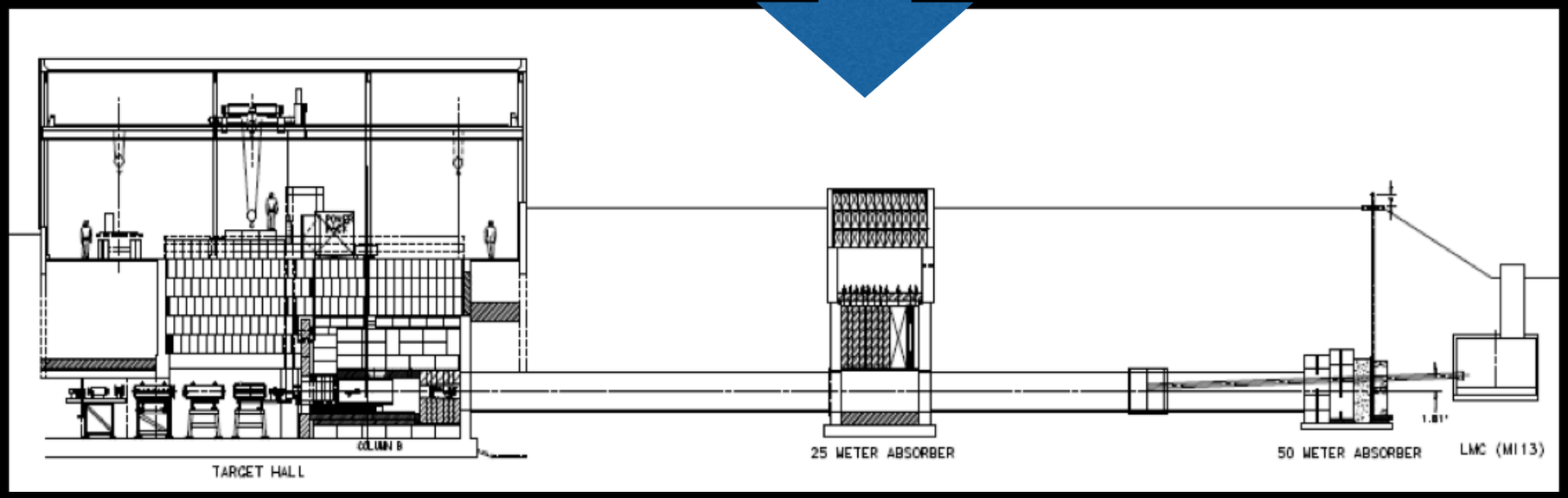


Target hall in MI 12 | 25m deployable absorber | 50m Fe dump

MiniBooNE: Dark Matter Mode

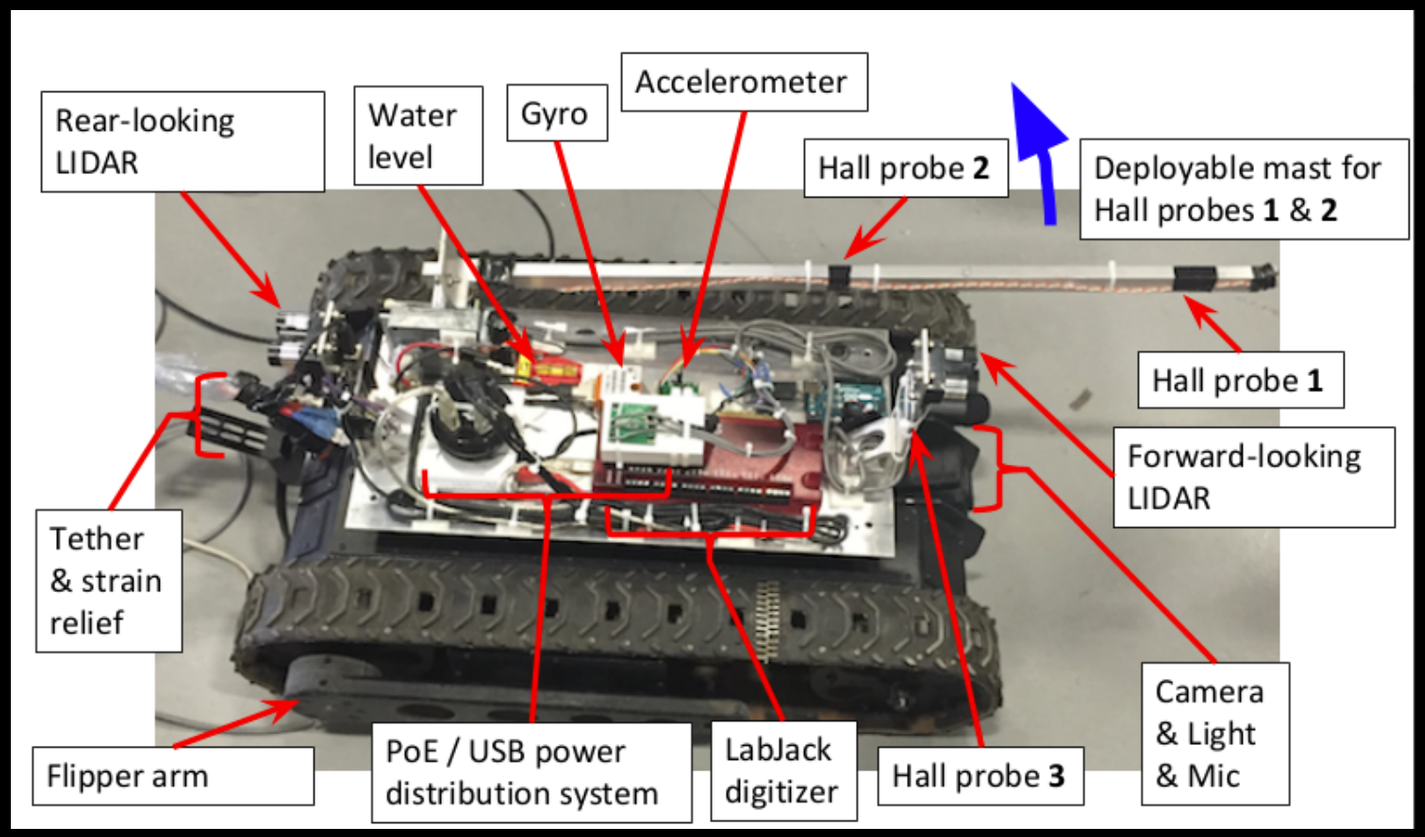
- Beam position/ alignment: Low intensity test beam to SWIC at 25 m

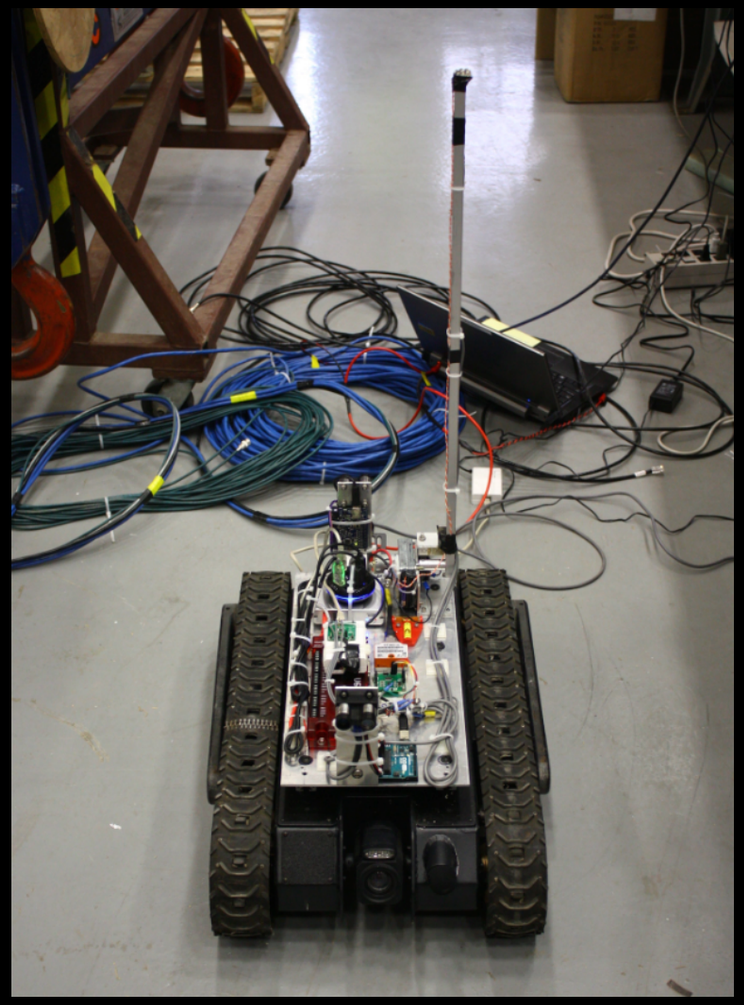




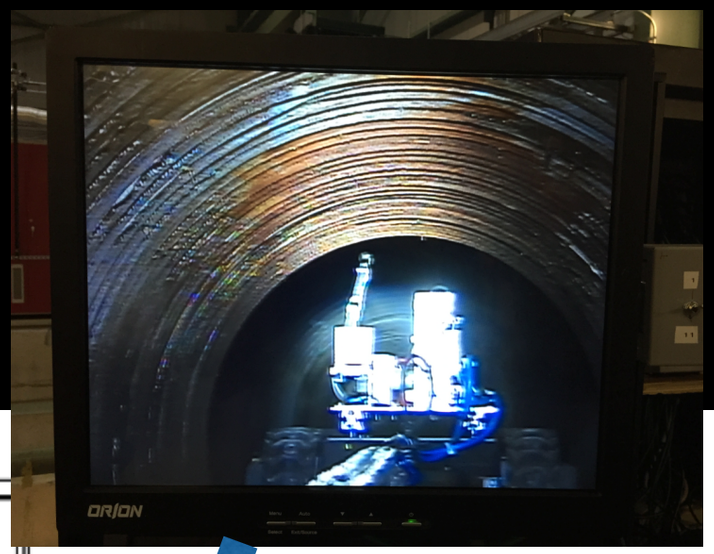
MiniBooNE: Dark Matter Mode

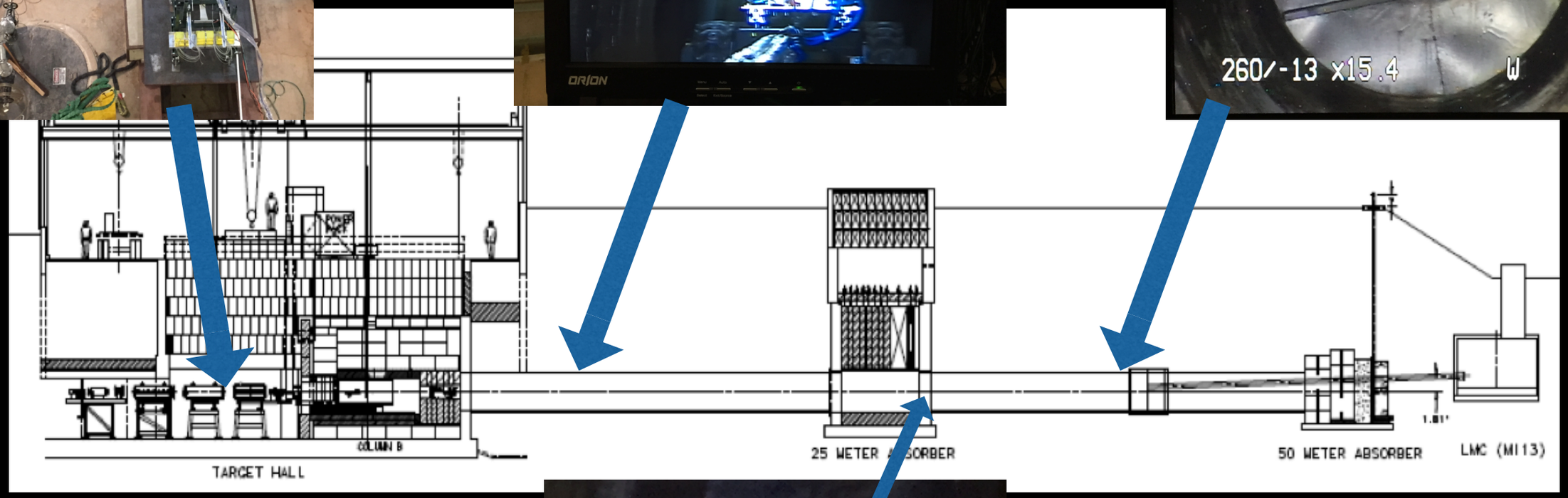
- Understanding the beam-off-target configuration
  - Beam position/alignment: Low intensity test beam to SWICs at 25 m
  - B field measurements and decay pipe inspection: Robot FRED





FRED: "Fermilab Robot for Exploration of Decay pipes"





MiniBooNE: Dark Matter Mode

- Understanding the beam-off-target configuration
  - Beam position/alignment: Low intensity test beam to SWICs at 25 m
  - B field measurements and decay pipe inspection: Robot FRED
  - Copper cables upgraded optic fibers to relay beam timing information

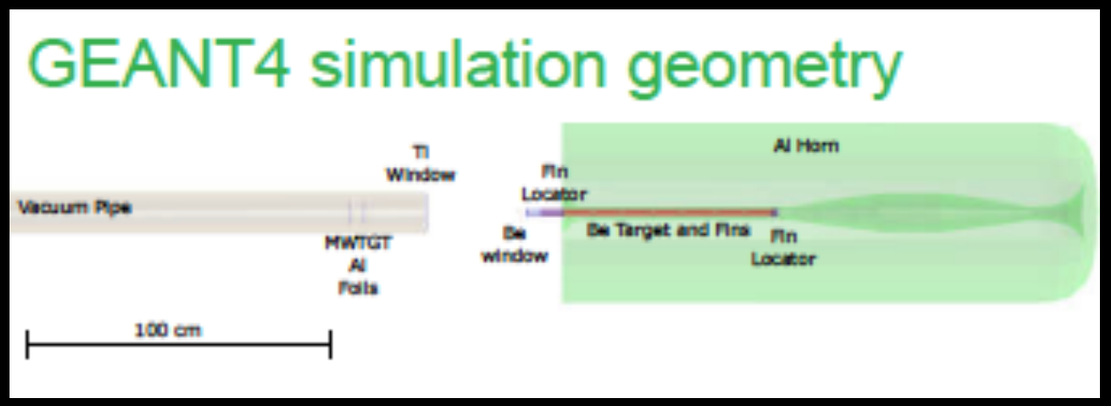
MiniBooNE: Dark Matter Mode

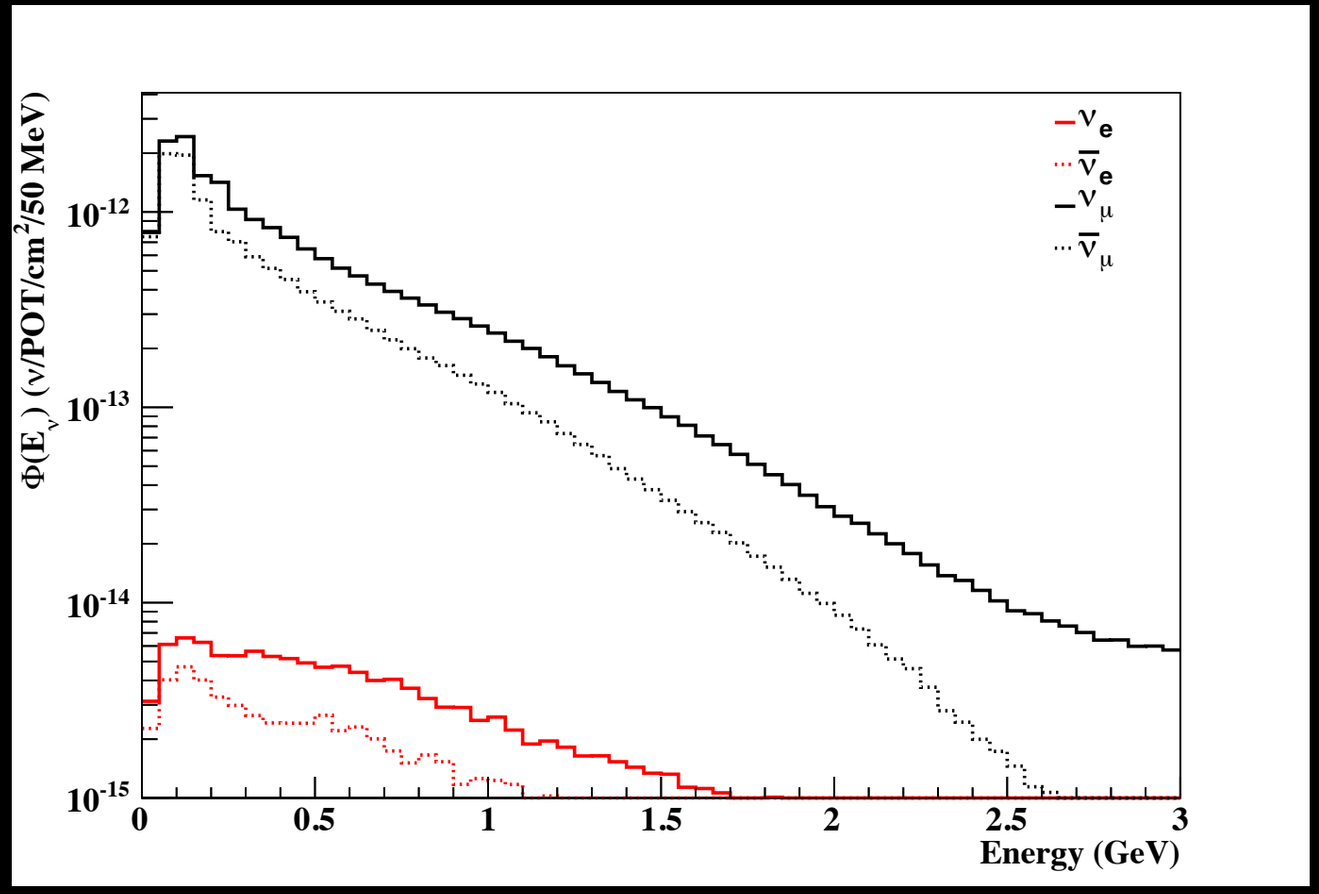
- Understanding the beam-off-target configuration
  - Beam position/alignment: Low intensity test beam to SWICs at 25 m
  - B field measurements and decay pipe inspection: Robot FRED
  - Copper cables upgraded optic fibers to relay beam timing information

MiniBooNE thanks Fermilab AD, Alignment and Beam for making these studies possible!

MiniBooNE Dark Matter Mode Flux prediction

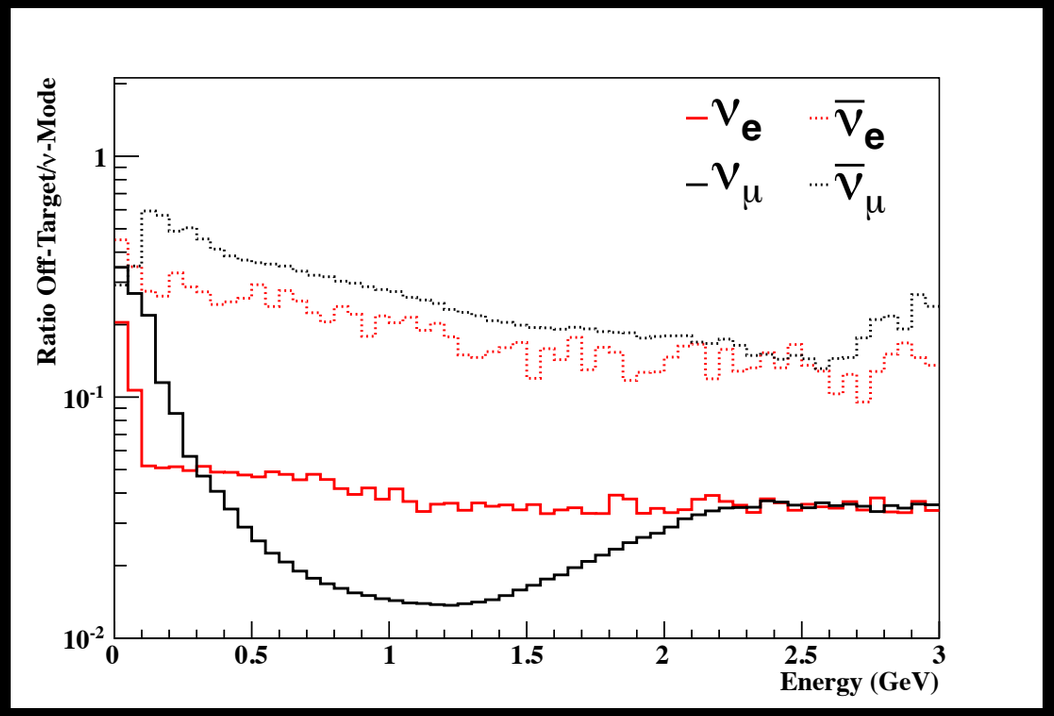
- Full beam line simulation GEANT4
- Included information from beam line studies
- Beam dump νCC rate for guide
- Neutrino flux suppressed by factor of ~27



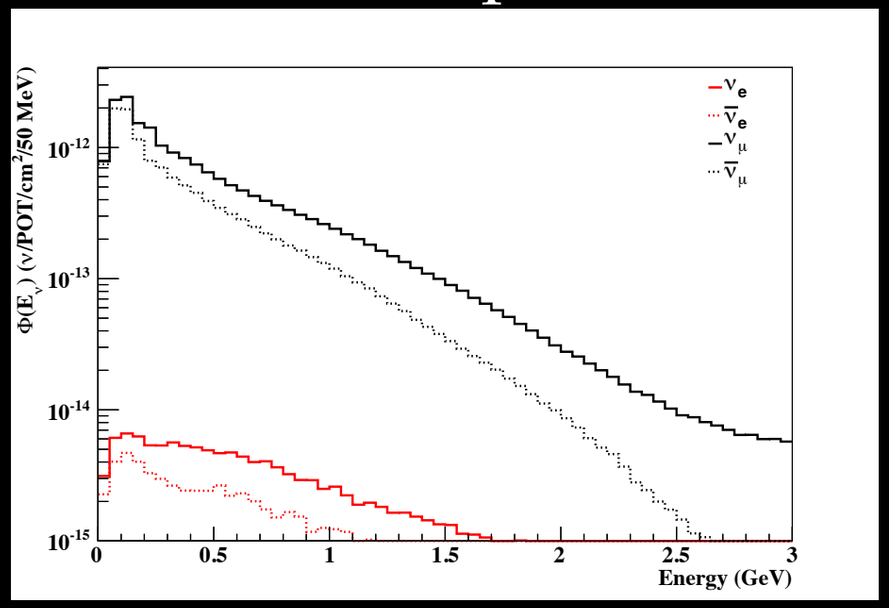


MiniBooNE Dark Matter Mode Flux prediction

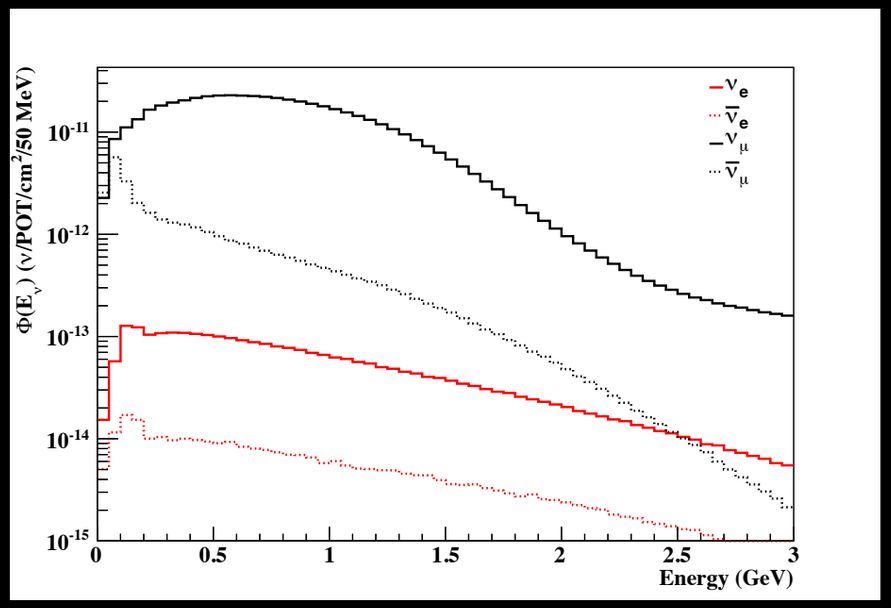
Ratio: beam off/ nu mode



Beam dump flux



Neutrino mode flux

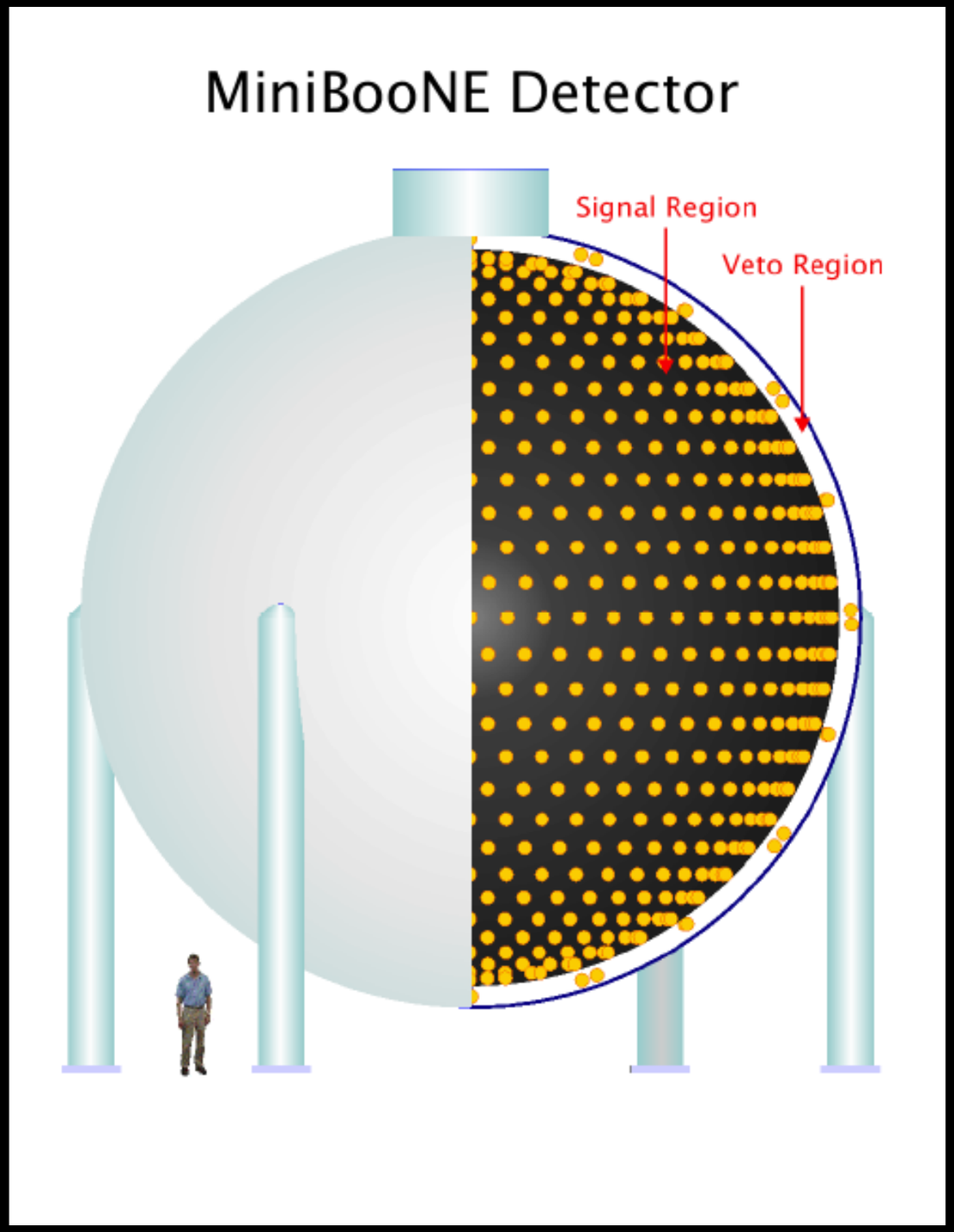


Phys. Rev. D79, 072002 (2009)

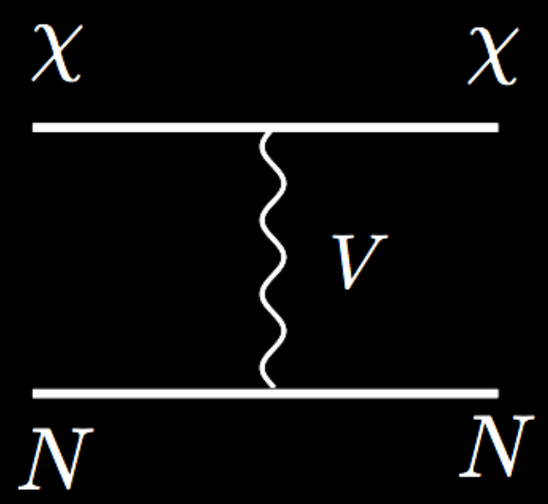
MiniBooNE Detector

- 541 meters from target
- 12 meter diameter sphere
- 800 tons mineral oil (CH_2)
- 3 m overburden
- Includes 35 cm veto region
- Viewed by 1280 8″ PMTs
- 10% coverage + 240 veto
- Simulated with GEANT3

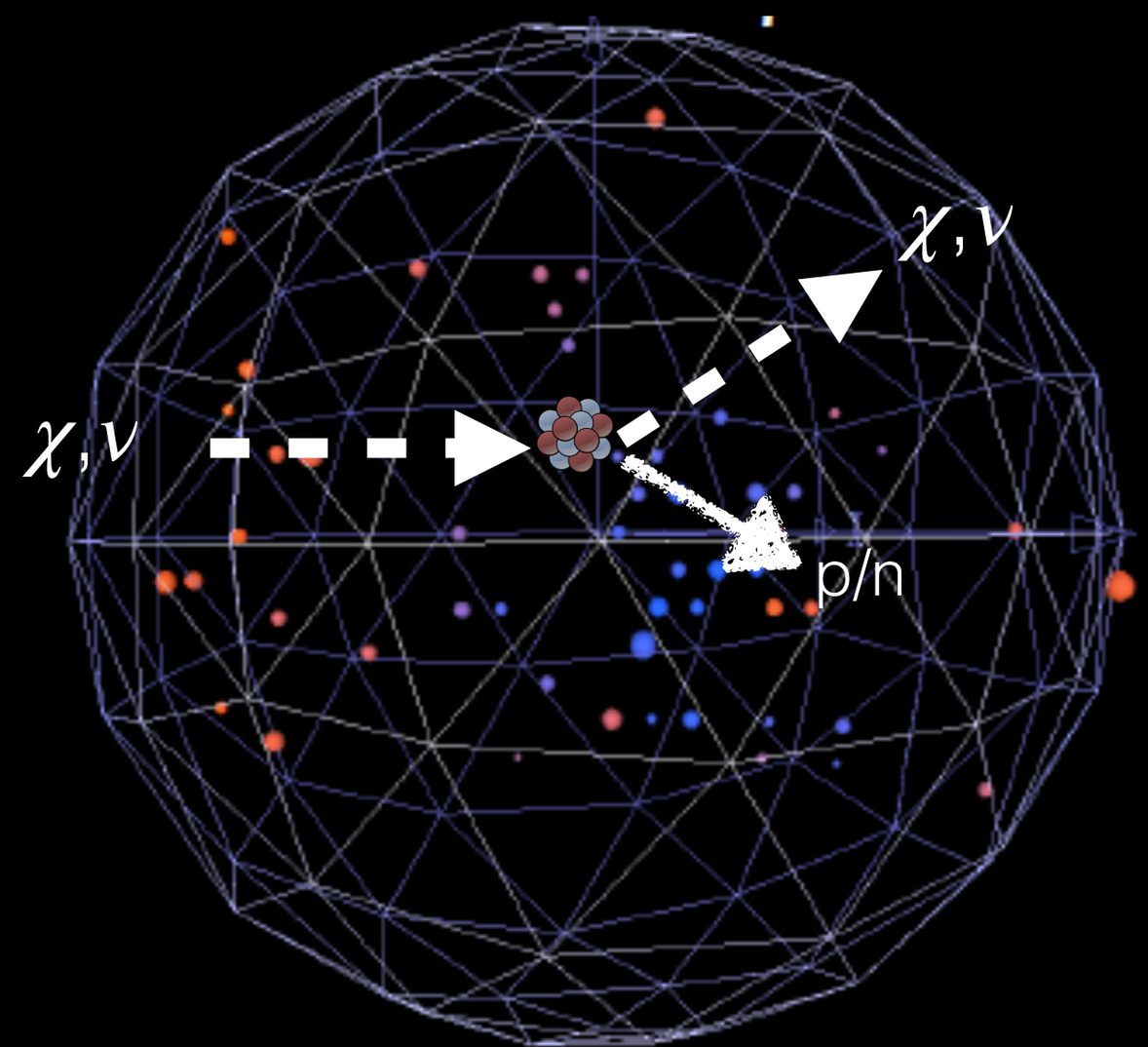
Nucl. Instr. Meth. A599 (2009)



MiniBooNE DM-Nucleon Analysis



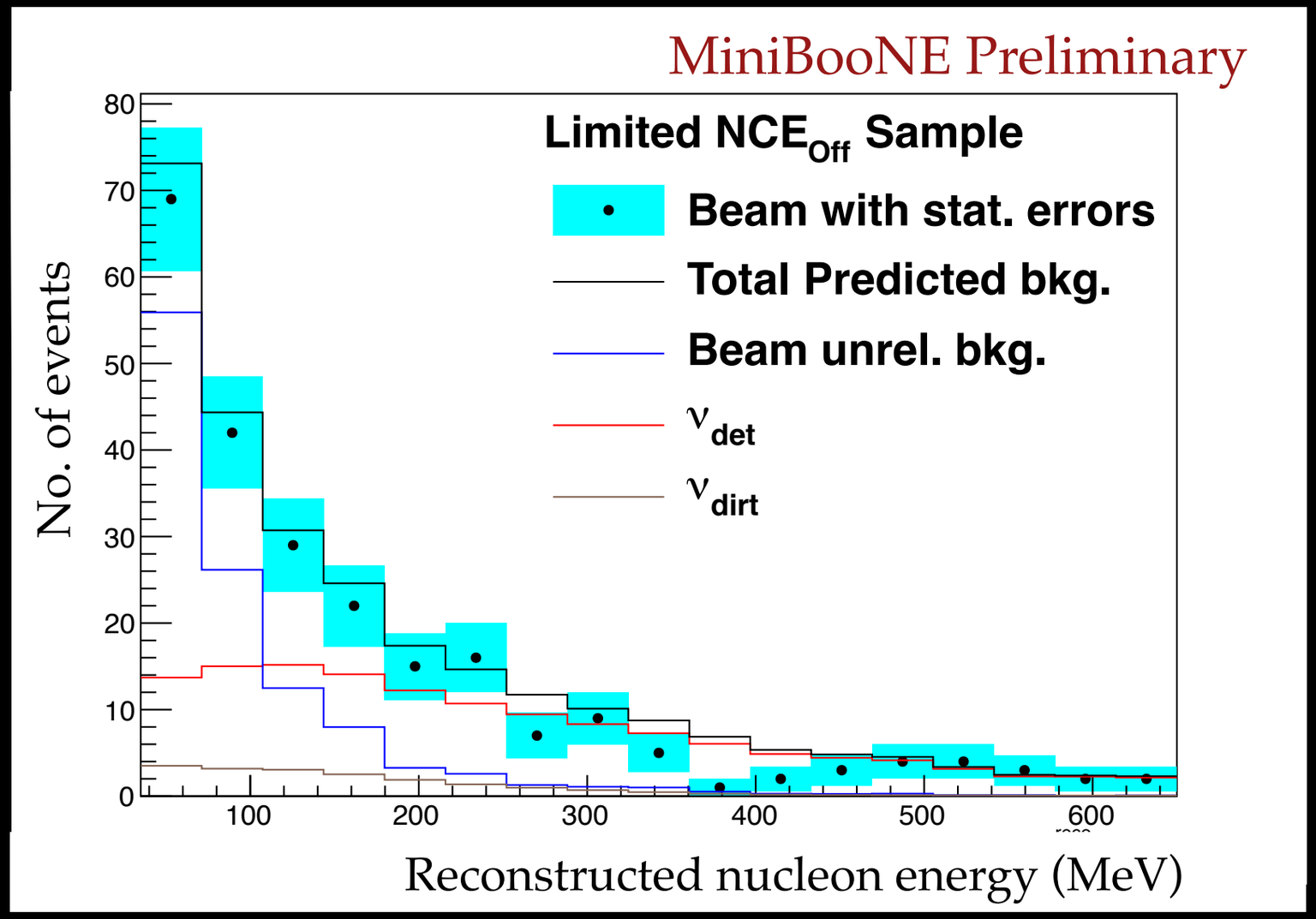
- Dark matter Neutral Current Elastic Analysis:tuned with 1/6 data (semi blind)
- Selection cuts to isolate single track proton-like events and reject beam related and cosmic backgrounds



- Protons detected by scintillation light
- Neutrons via secondary scatter off protons

MiniBooNE DM-Nucleon Analysis

- Look at 1/6 data set. DM candidate events
- Major backgrounds:
  - Beam unrelated cosmics
  - Beam related "dirt" (neutrino induced outside of detector)
  - Beam related detector events



- Projected errors for full sample:
  - 3% statistical
  - 10% systematic

MiniBooNE DM-Nucleon Analysis

- Analysis strategy: Leverage 10+ years of MB running to constrain the errors.
- "Double ratio" method:

Reduces cross section systematic

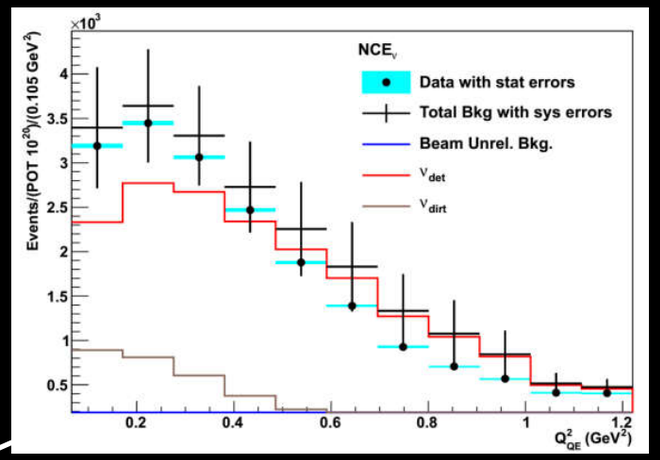
$$\frac{N_{(NC\text{-}DM)} \,/\, N_{(NC\text{-}\nu)}}{N_{(CC\text{-}DM)} \,/\, N_{(CC\text{-}\nu)}}$$

Reduces flux systematic

NCE-DM: Neutral Current Elastic events in beam-dump data
NCE-ν : Neutral Current Elastic events in neutrino mode data
CC-DM: Charged Current Elastic events in beam-dump data
CC-ν: Charged Current Elastic events in neutrino mode data

MiniBooNE DM-Nucleon Analysis

- Analysis strategy: Leverage 10+ years of MB running to constrain the errors.
- "Double ratio" method:

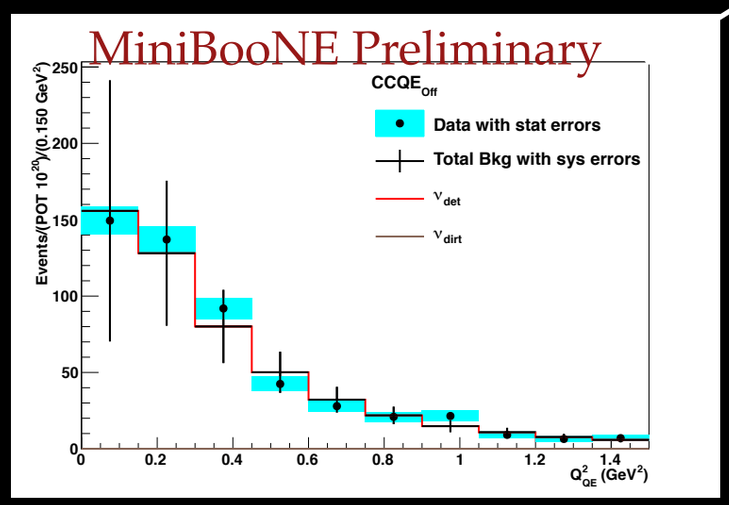


Phys. Rev. D82, 092005 (2010)

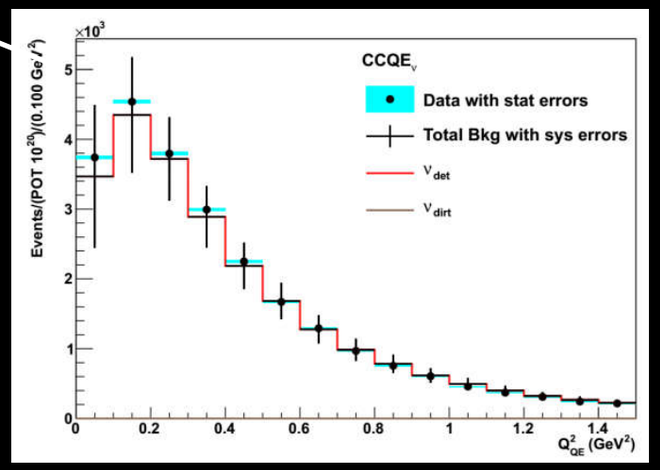
Reduces cross section systematic

$$\frac{N_{(NC\text{-}DM)} / N_{(NC\text{-}\nu)}}{N_{(CC\text{-}DM)} / N_{(CC\text{-}\nu)}}$$

Reduces flux systematic

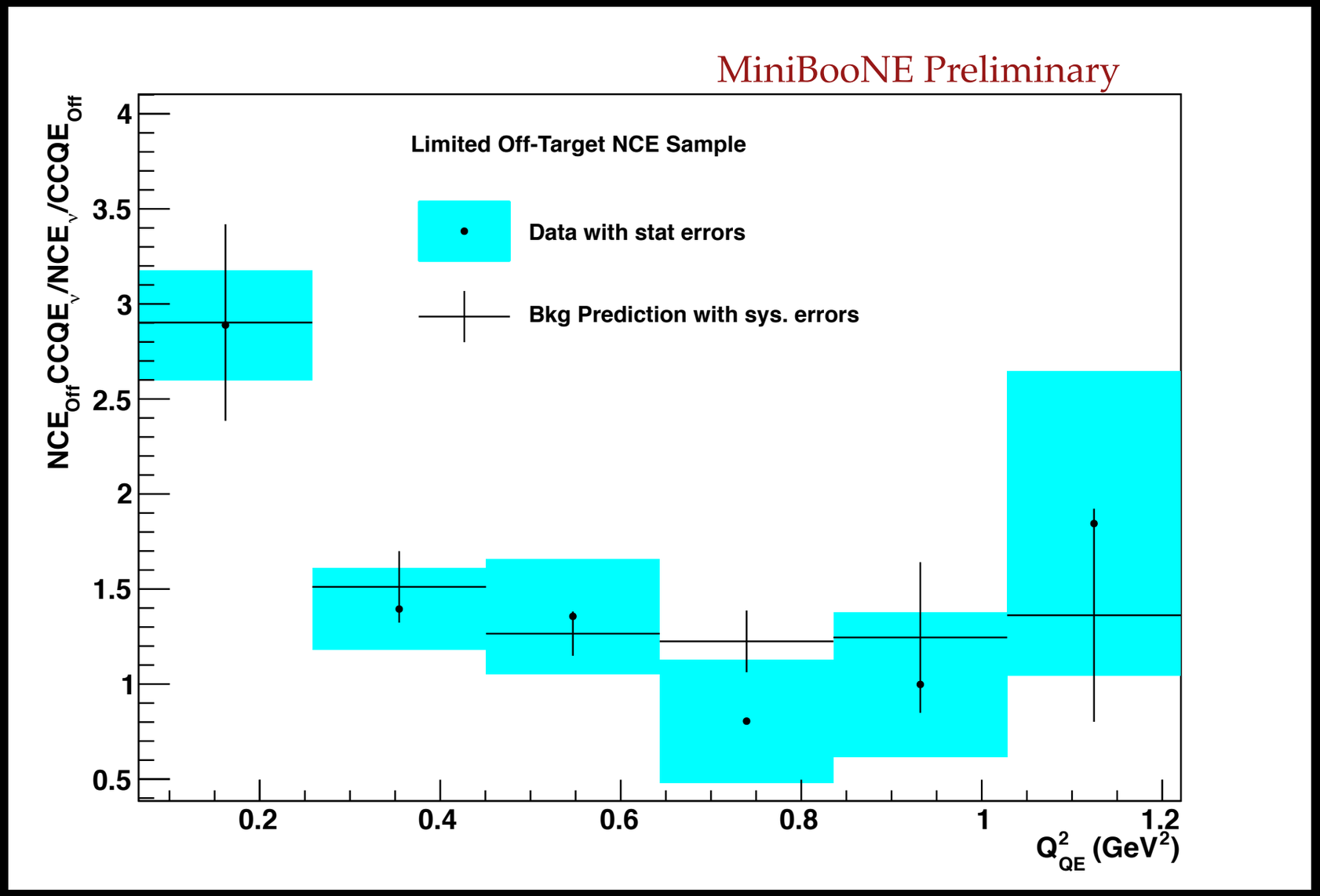


Phys. Rev. D81, 092005 (2010)



MiniBooNE DM-Nucleon Analysis

- Limited sample double-ratio

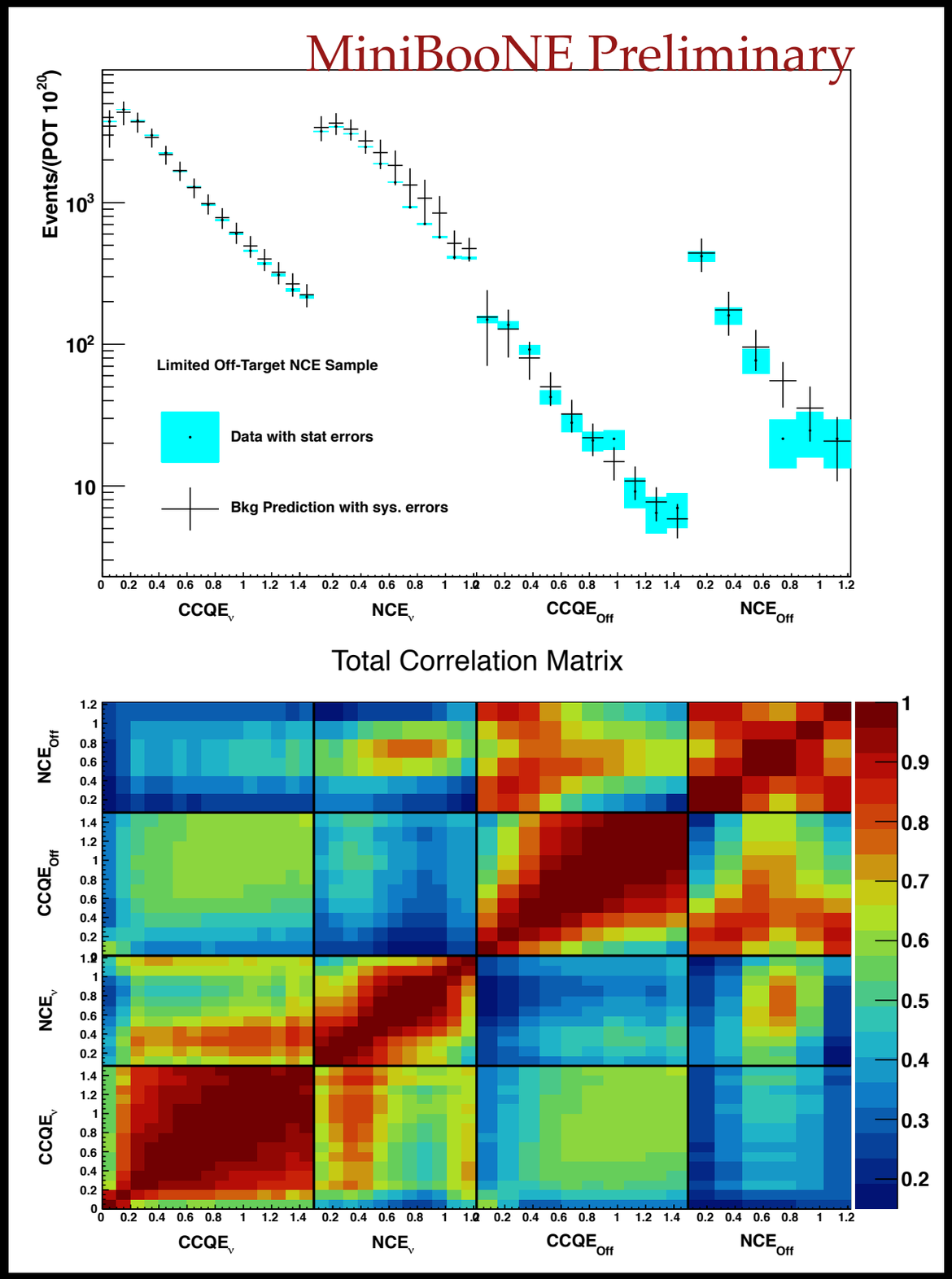


MiniBooNE DM-Nucleon Analysis

- Will do combined fit to(neutrino/ off-target) X (CCQE, NCE)samples
- Correlated errors considered

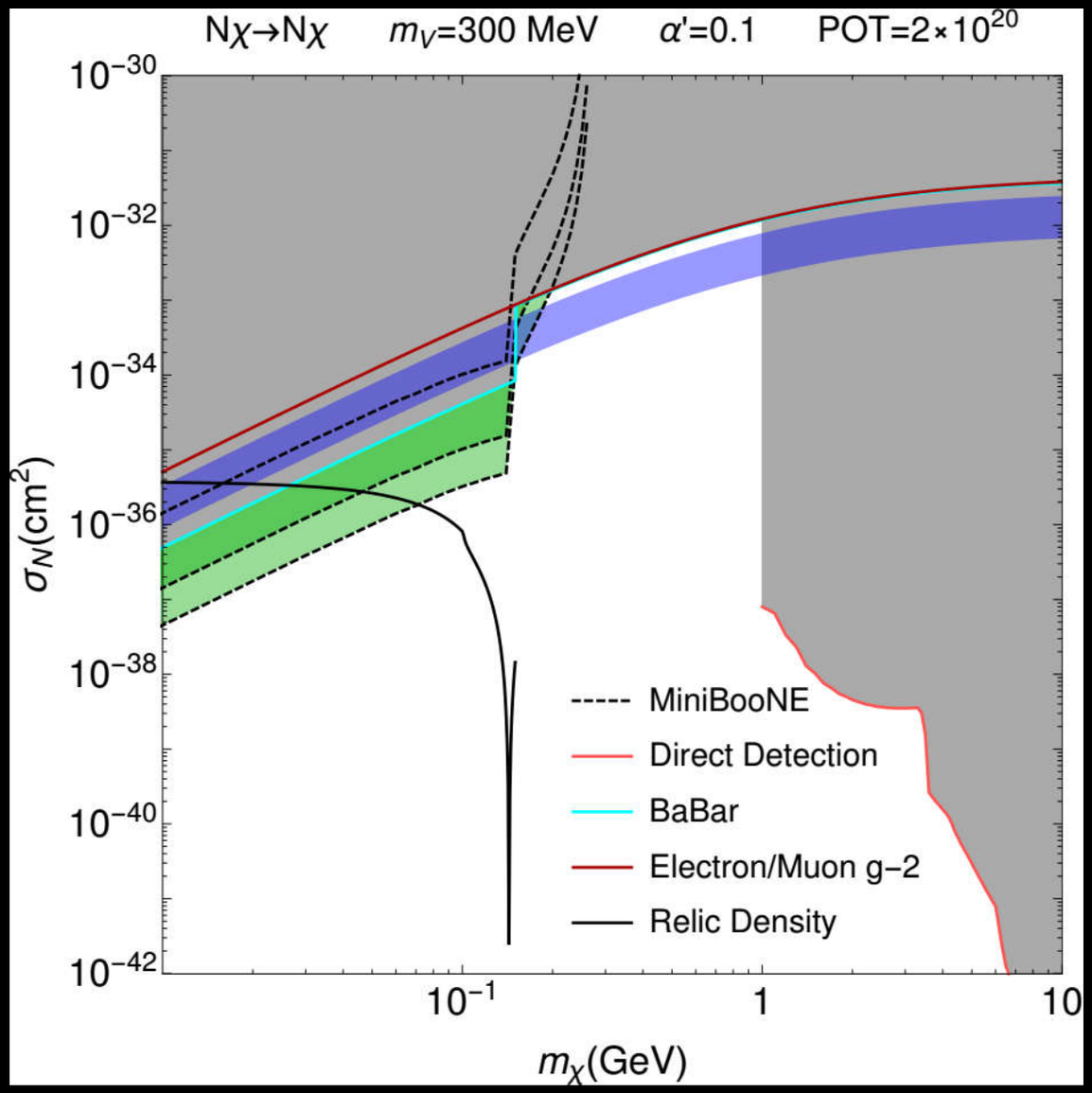
Fit with:

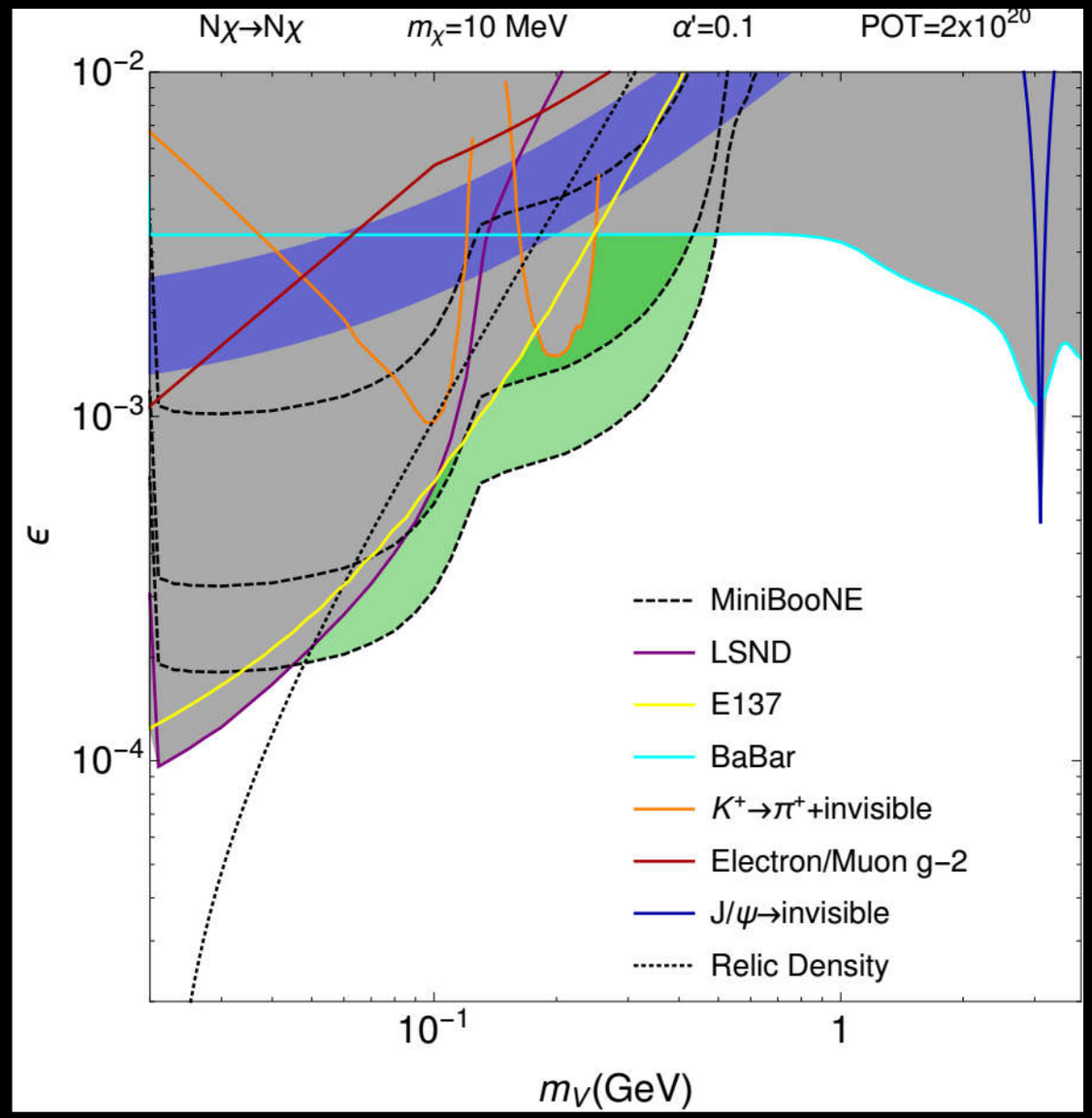
- Nuisance parameters:
  - flux scale factor
  - CCQE/NCE cross section corrections
- Physics parameters:
  - mχ: dark matter mass
  - mV: new vector mass
  - ϰ : coupling between DS and SM
  - α′ : new electromagnetic coupling



MiniBooNE DM-Nucleon Analysis

- Expected sensitivity



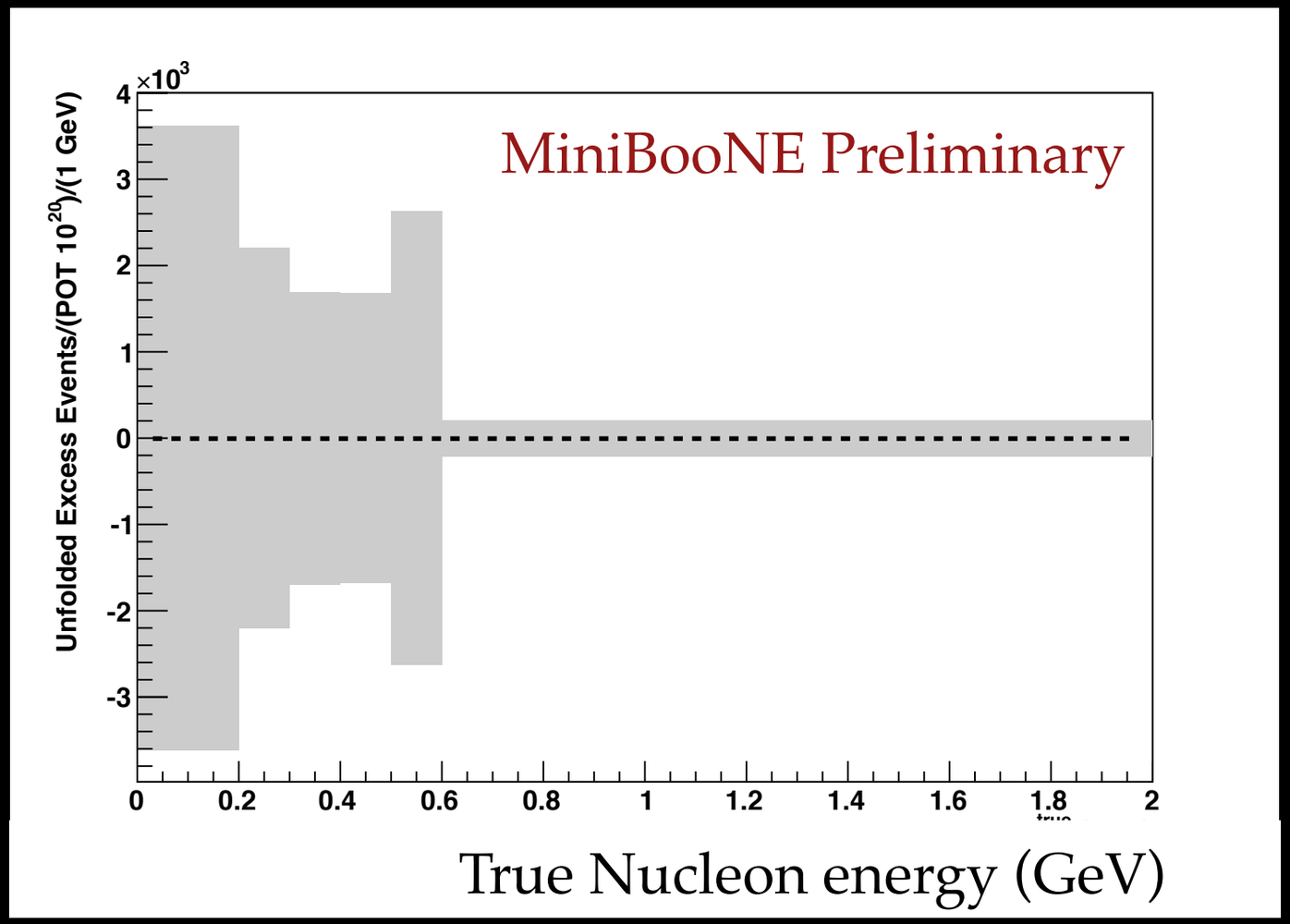


green shaded regions: 1-10, 10-1000 observed events in MiniBooNE

Plots by Patrick deNiverville (University of Victoria)

DM-NCE Analysis

- Will report on model independent excess
- Together with flux and detector systematics will allow theorists to test other models



MiniBooNE: Dark Matter Mode

- This talk: preview of DM- nucleon scattering
- Analysis by R. Tyler Thornton (Indiana U). Full results coming soon!

MiniBooNE: Dark Matter Mode

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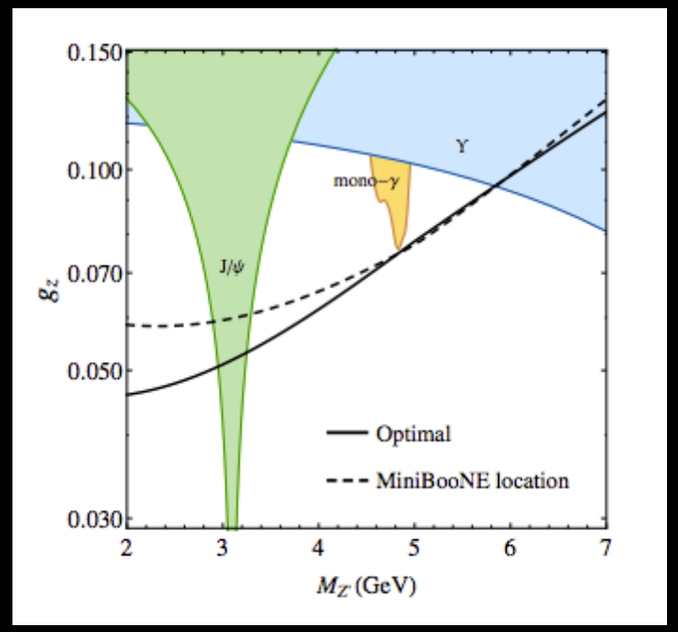
  Full results coming soon!

- Also other channels: DM-e, DM-Δ (pi0)

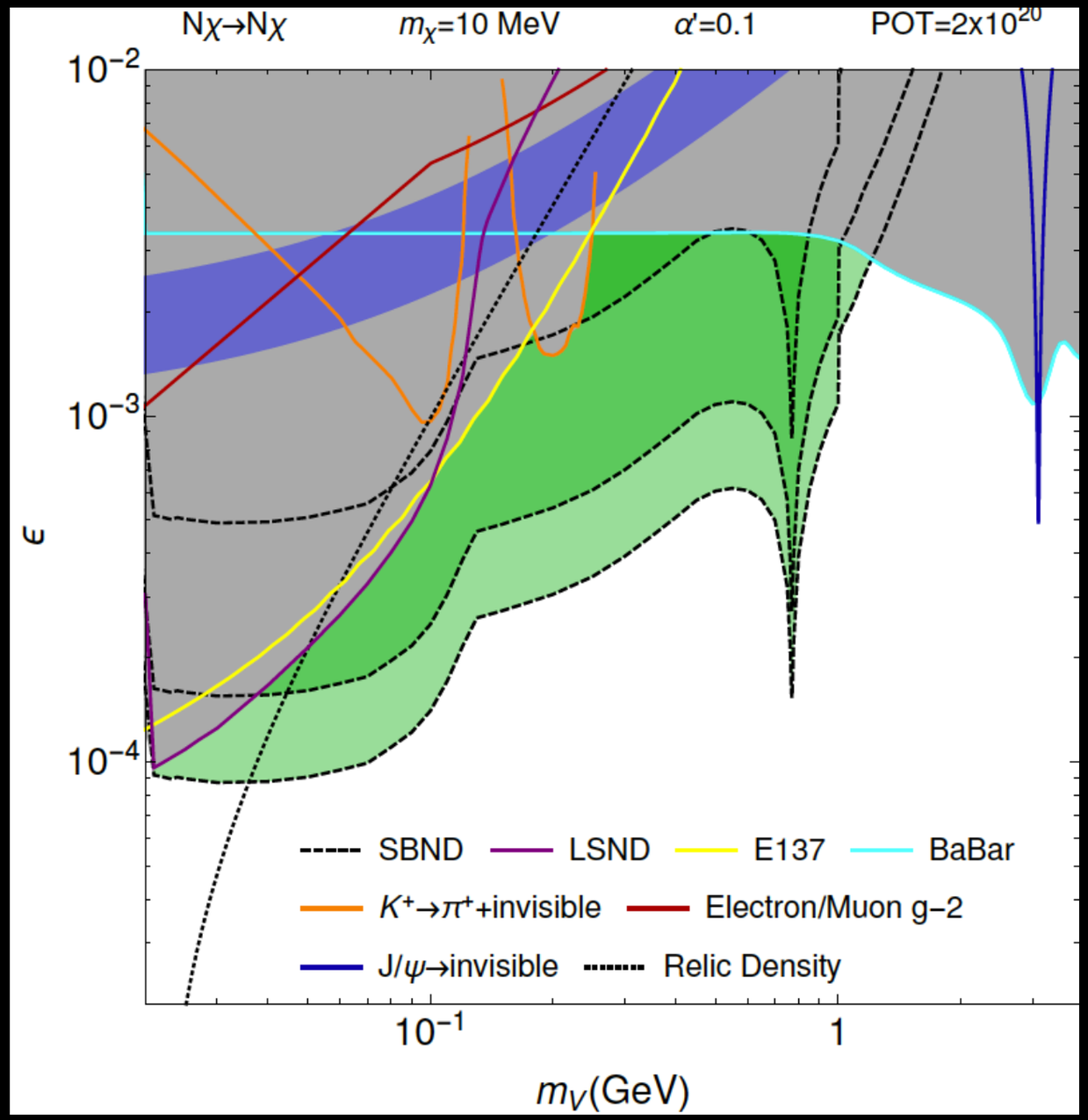
- Higher mass DM from NUMI beam in MiniBooNE

arXiv:1512.03852

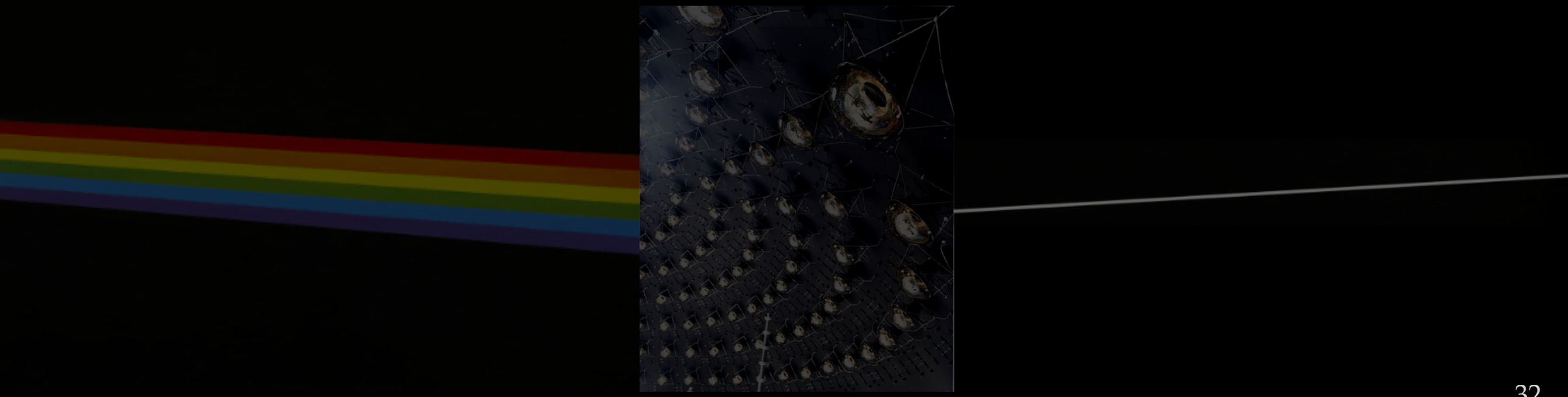


Future: Dark Matter Search at SBN

- SBND detector nearer to the dump



Plot by Patrick deNiverville (University of Victoria)

Summary:

- MiniBooNE has successfully employed a neutrino detector to search for dark matter.
- Results of the DM-Nucleon scattering search will be presented soon and paper in the works.