Novel constraints to recent MiniBooNE explanations: Laying siege to new physics

Carlos A. Argüelles

also starring

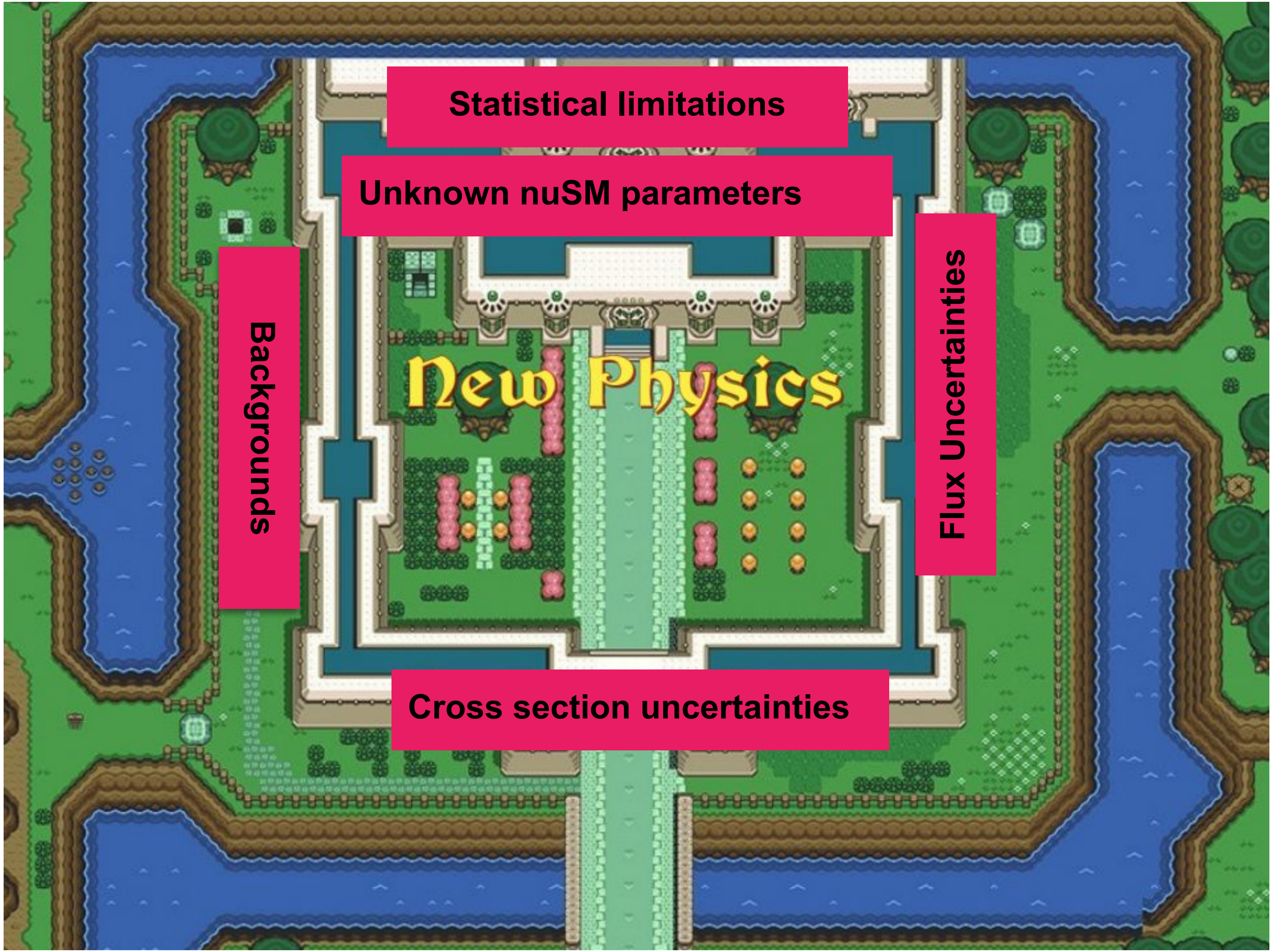
Matheus Hostert (Durham) and Yu-Dai Tsai (FNAL)

Siege

noun

a military operation in which enemy forces surround a town or building, cutting off essential supplies, with the aim of compelling the surrender of those inside.


New Physics


Statistical limitations
Unknown nuSM parameters
Backgrounds
New Physics
Flux Uncertainties
Cross section uncertainties

The MiniBooNE excess

The MiniBooNE excess is an electron-neutrino-like observation above SM backgrounds. Explanation ideas:

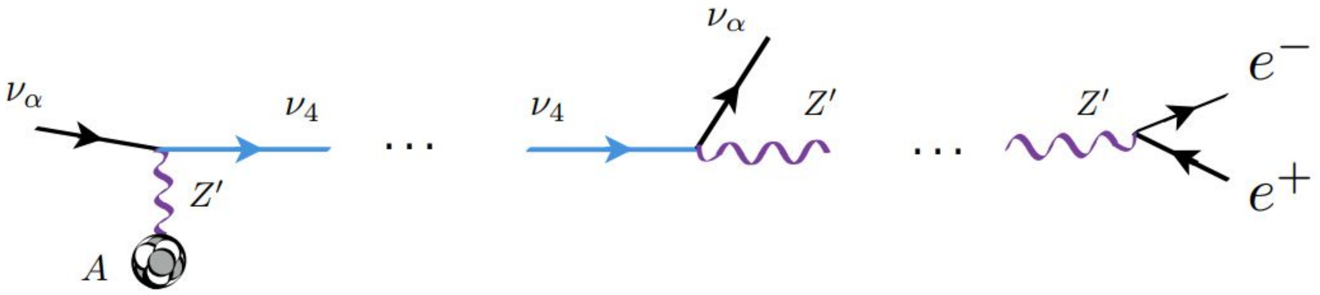
- More electron-neutrino: P(\nu_\mu \to \nu_e) > 3nuSM prediction. Sterile neutrino*?
- Electron-like background: more gammas?

- Recent proposal: new neutrino interaction that produces a pair of electrons.

* see talk tomorrow by C. Ternes@PONDD for a status on this; for tension and recent status with sterile neutrino explanations see Dentler et al. 1803.10661; also check out Moss et al. 1711.05921, Liao et al. 1810.01000, and Denton et al. 1811.01310 for recent ideas on how to get around these problems. See also Esmaili et al. 1810.11940 for complications with some of these ways out.

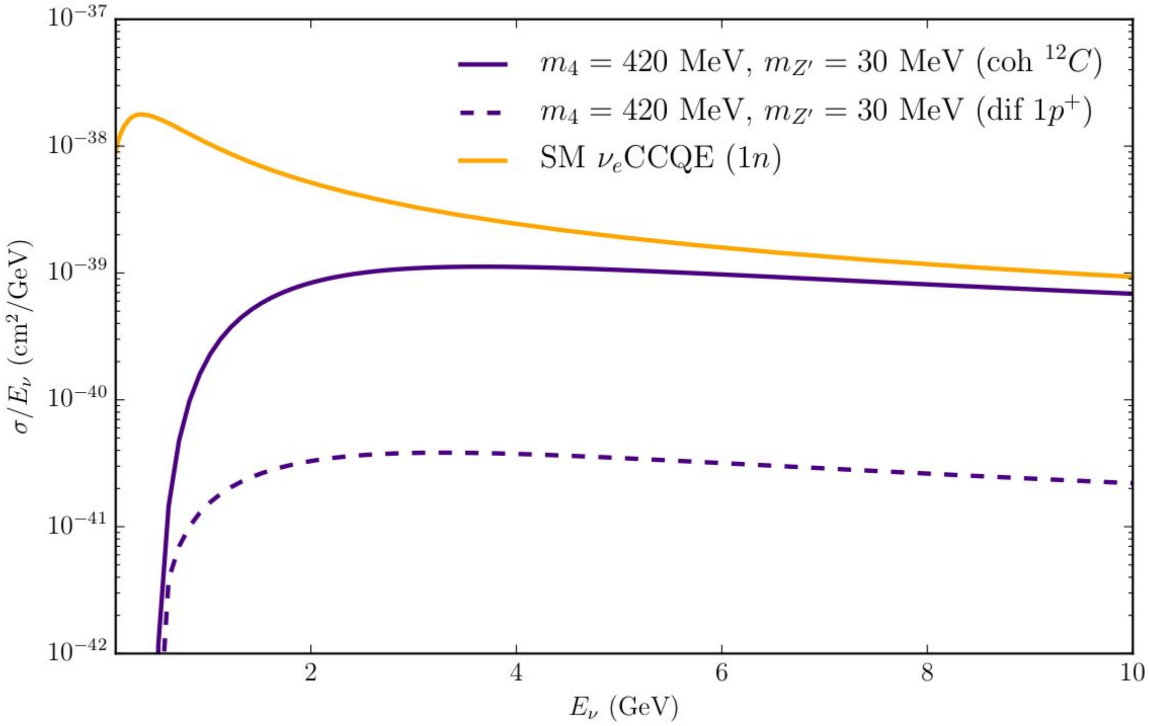
New proposal key features

- Little/no hadronic activity [depends on ratio of diffractive to coherent contributions]
- Small angular separation wrt to the booster beam. (see arXiv:1303.4587 and arXiv:1705.00353 for problems with angular distributions)
- Energy distribution must fit the excess observation.



See Bertuzzo et al. 1807.09877 and similar model by Ballett et al. 1808.02915.

How big of a cross section are we talking about?



Note that CCQE is per nucleon;

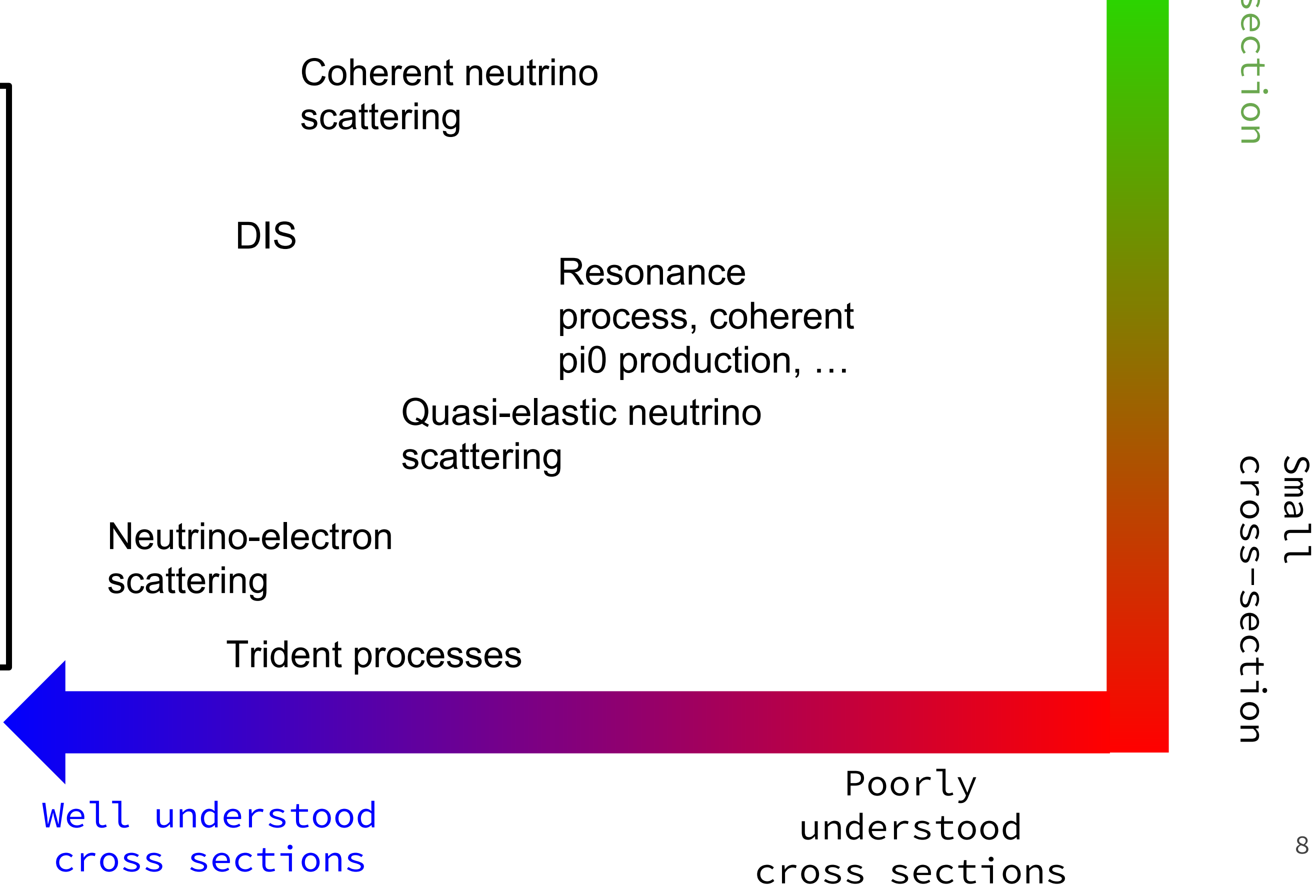
BSM-coh is per atom.

Here we use benchmark (BP) point parameters reported by Bertuzzo et al. 1807.09877.

Strategy

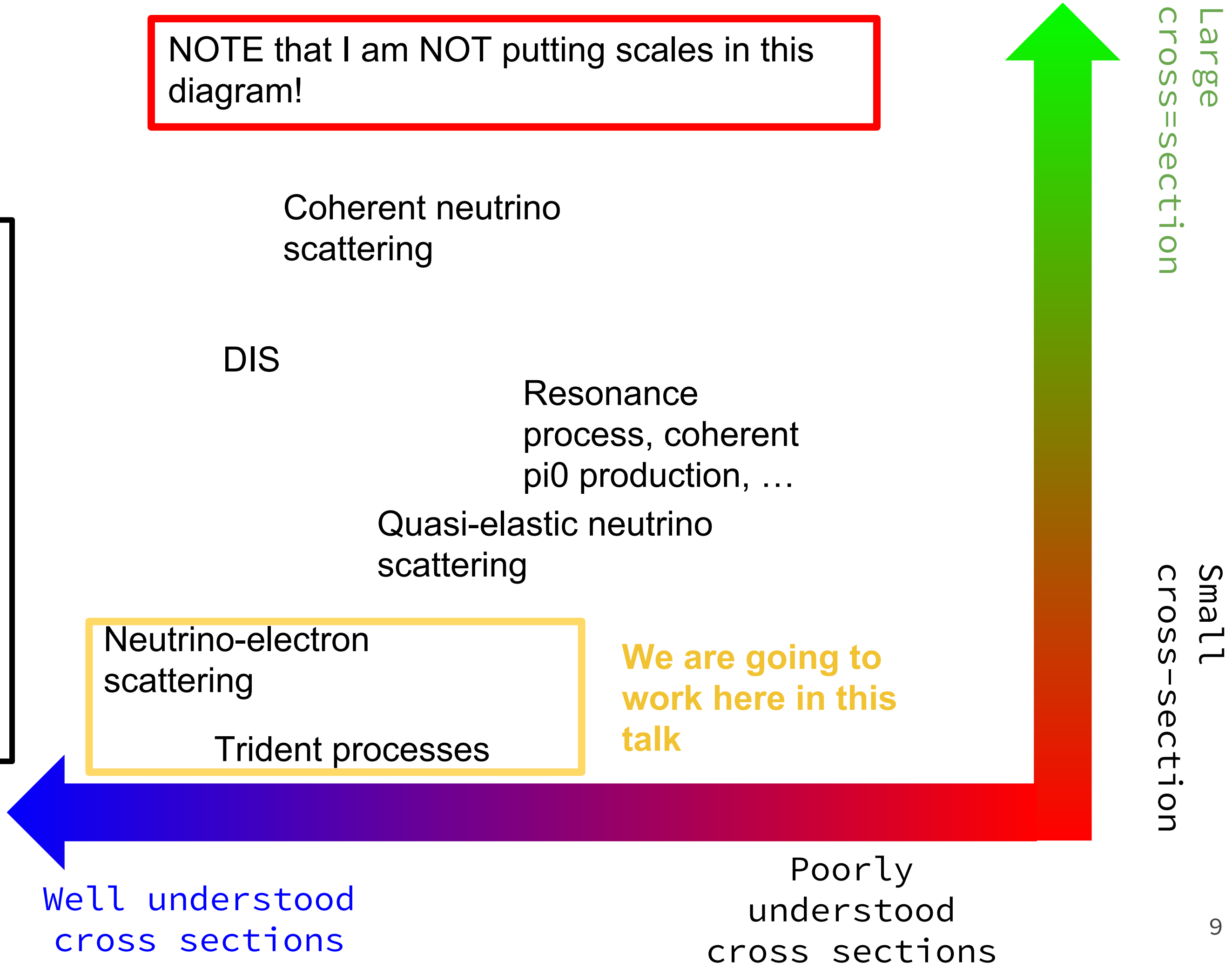
NOTE that I am NOT putting scales in this diagram!

Looking for novel neutrino interactions requires understanding of our SM neutrino interactions. This is tough; see e.g. talks on Monday.



Strategy

Looking for novel neutrino interactions requires understanding of our SM neutrino interactions. This is tough; see e.g. talks on Monday.



Neutrino-electron scattering measurements

We have measured neutrino-electron scattering @:

- **LSND**
- **TEXONO**
- **Borexino**
- **SuperK**
- **MINERvA Low-Energy**
- **CHARM-II**

Too low energies for BSM case of interest

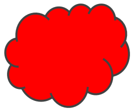
We will focus on these experiments.

Will measure it very soon @ **MINERvA Medium-Energy, NOvA,**

and later @ **DUNE**.

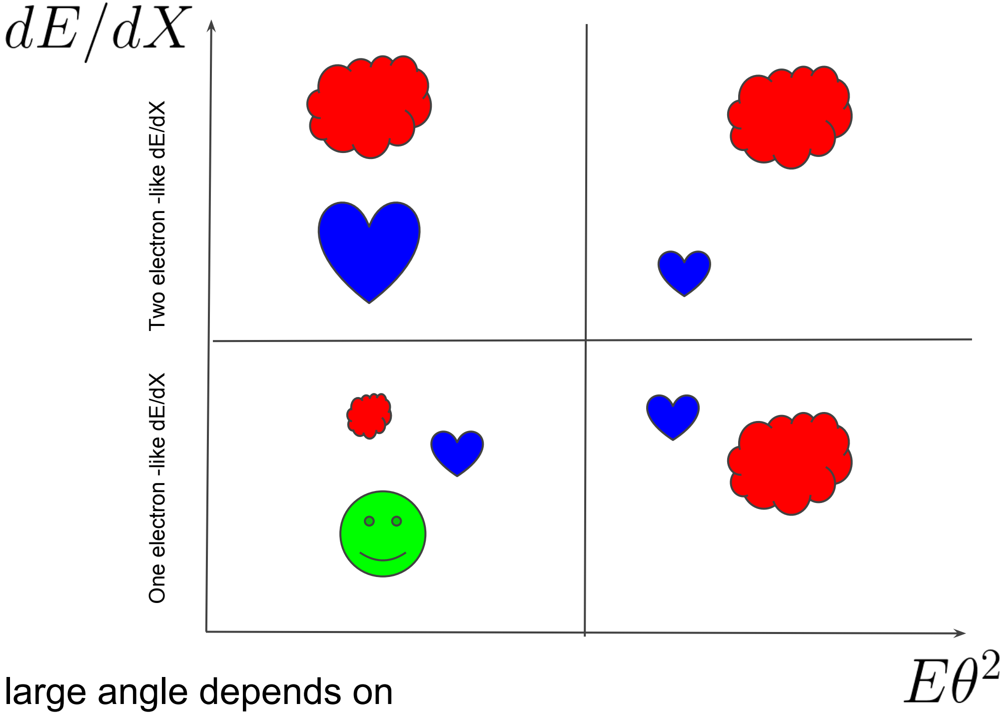
Strategy

Electron-neutrino-like scattering search

 Background, e.g. NCpi0

 Neutrino-electron scat.

 Recent BSM-MB explanations

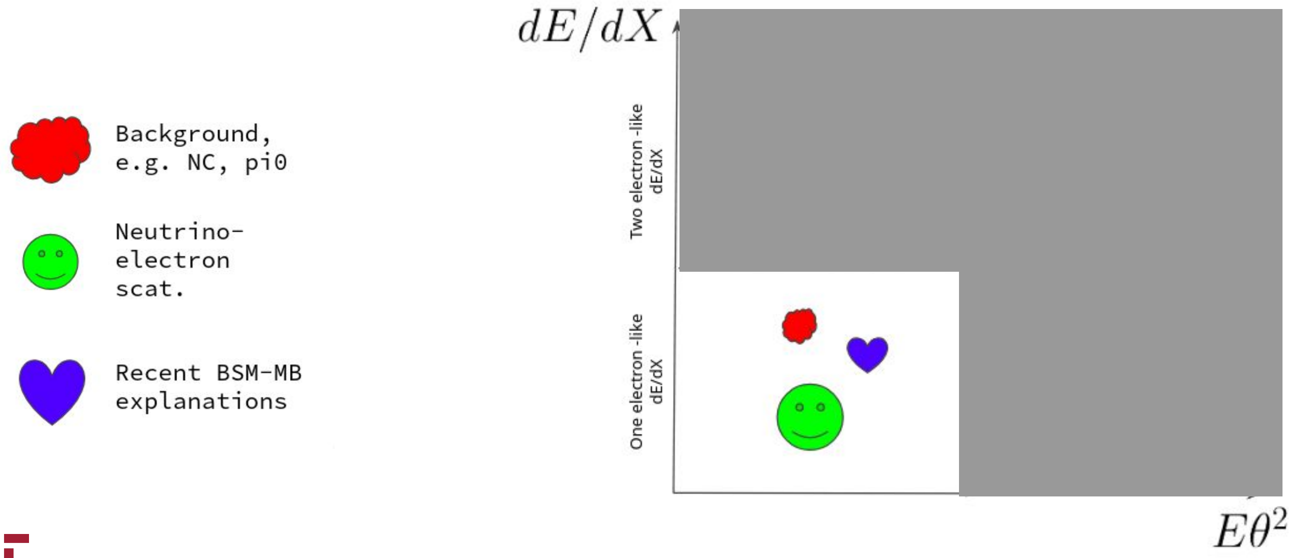


*how much *leakage* onto the large angle depends on model parameter and neutrino energy.

Working around limited information!

By design at final cut level CHARM-II and Minerva measurements have small backgrounds: also means small amount of BSM-signal leaking in. We cannot use the final event samples to constrain the new models **:(!**

Would be great if we had access to the reconstructed electron energy and angular distributions at different cut levels.



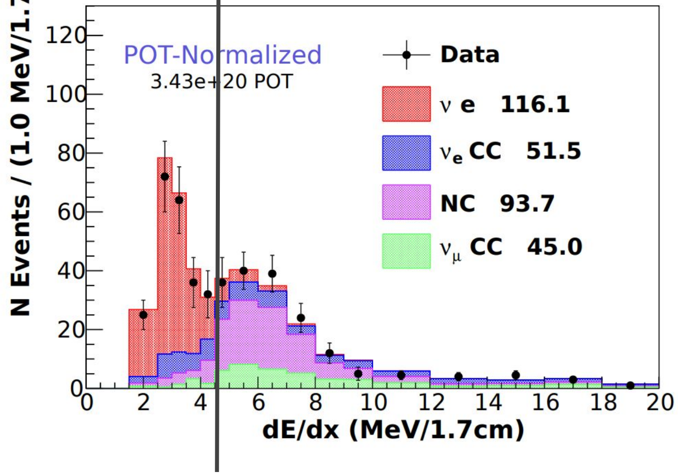
MINERvA analysis strategy

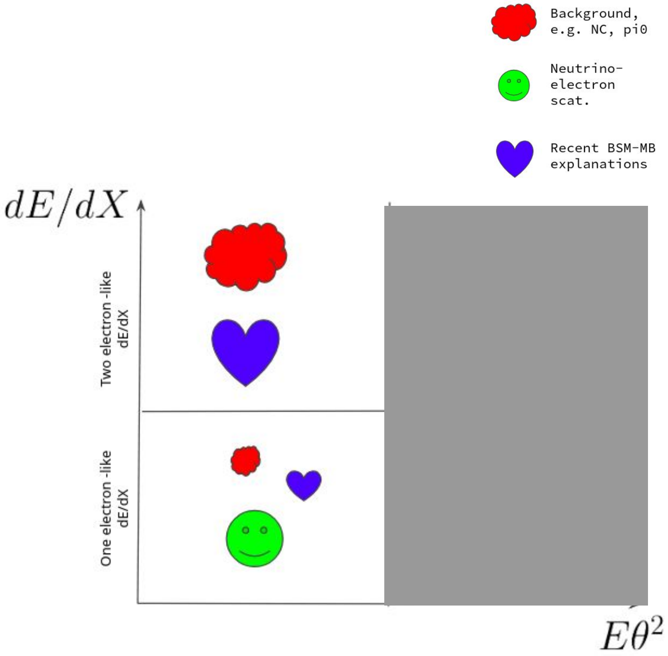
For MINERvA we are going to use the dE/dX distribution of candidate electron-neutrino scattering events.

All MINERvA cuts applied, except for the final dE/dX cut!

Note that backgrounds have been tuned here!

BSM signal lives here, but background too!





Minerva Collaboration
Phys. Rev. D 93, 112007 (2016)

MINERvA analysis strategy

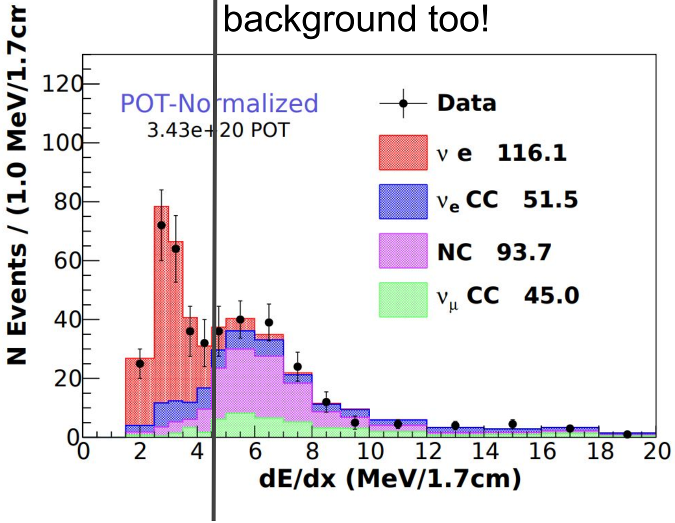
Parameter	Tuned value
ν_e	0.76 ± 0.03
ν_μ NC	0.64 ± 0.03
ν_μ CC	1.00 ± 0.02

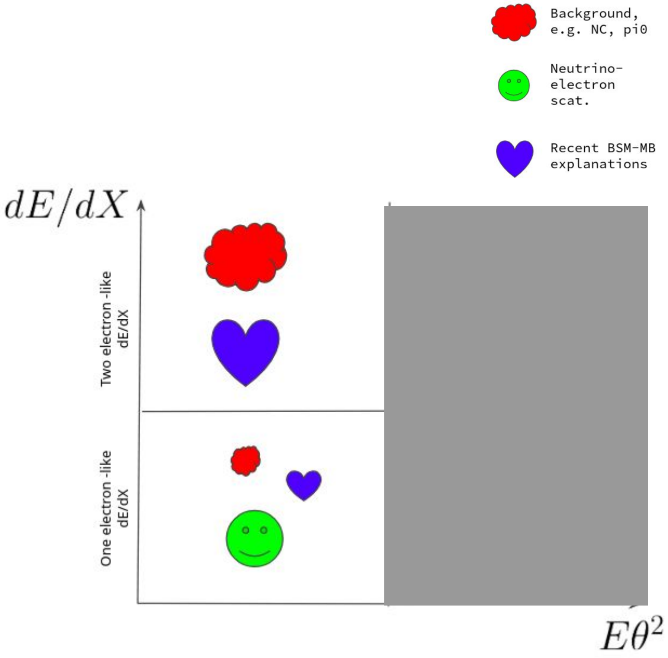
For MINERvA we are going to use the dE/dX distribution of candidate electron-neutrino scattering events.

All MINERvA cuts applied, except for the final dE/dX cut!

Note that backgrounds have been tuned here!

BSM signal lives here, but background too!



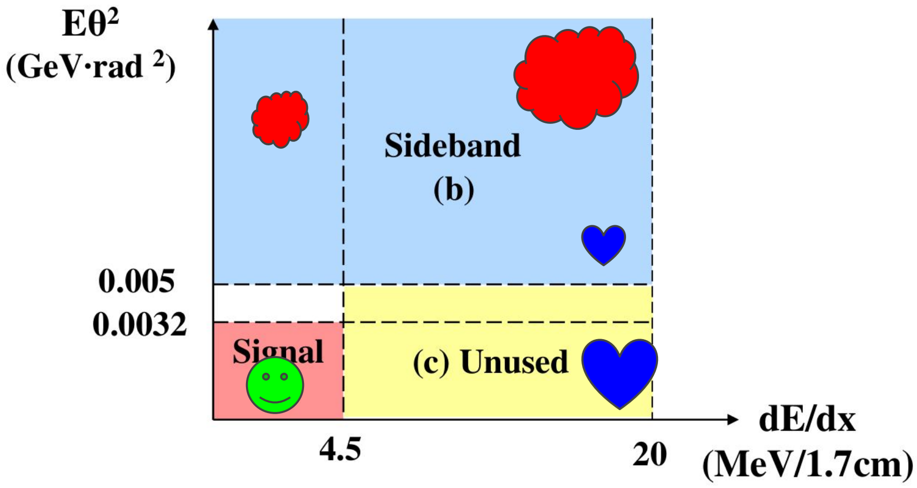


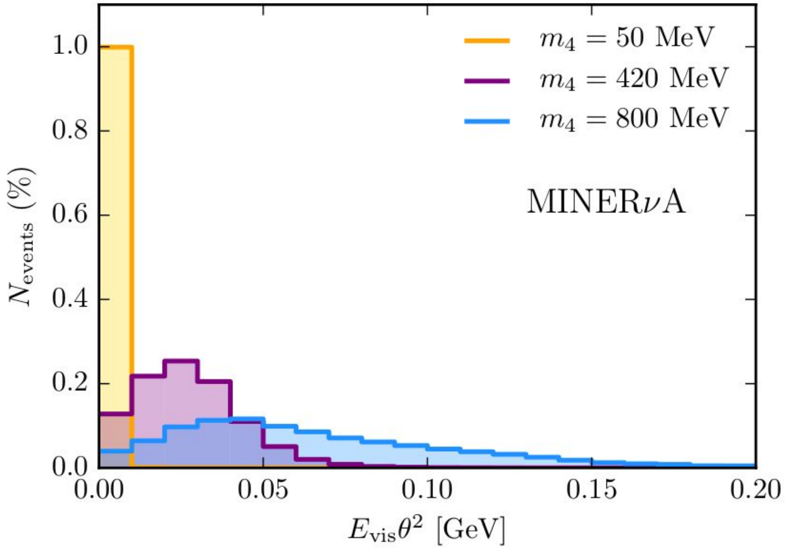
Minerva Collaboration
Phys. Rev. D 93, 112007 (2016)

Tunning parameters table from J. Park thesis:
http://lss.fnal.gov/archive/thesis/2000/fermilab-thesis-2013-36.pdf

Sidebans used for tuning background on Minerva

Tunning parameters diagram from J. Park thesis:
http://lss.fnal.gov/archive/thesis/2000/fermilab-thesis-2013-36.pdf





For large heavy neutrino masses the BSM contribution leaks the sideband used to constrain the background on the neutrino electron scattering region.

Minerva: Our Analysis setup

We use the following \chi^2 definition:

$$\chi^2_{\alpha\beta} = \frac{(N_{\rm data} - (1+\alpha+\beta)\mu^{\rm BKG}_{\rm MC} - (1+\alpha)\mu^{nu-e}_{\rm MC} - (1+\alpha)\mu_{\rm BSM})^2}{N_{\rm data}} + \left(\frac{\alpha}{\sigma_\alpha}\right)^2 + \left(\frac{\beta}{\sigma_\beta}\right)^2$$

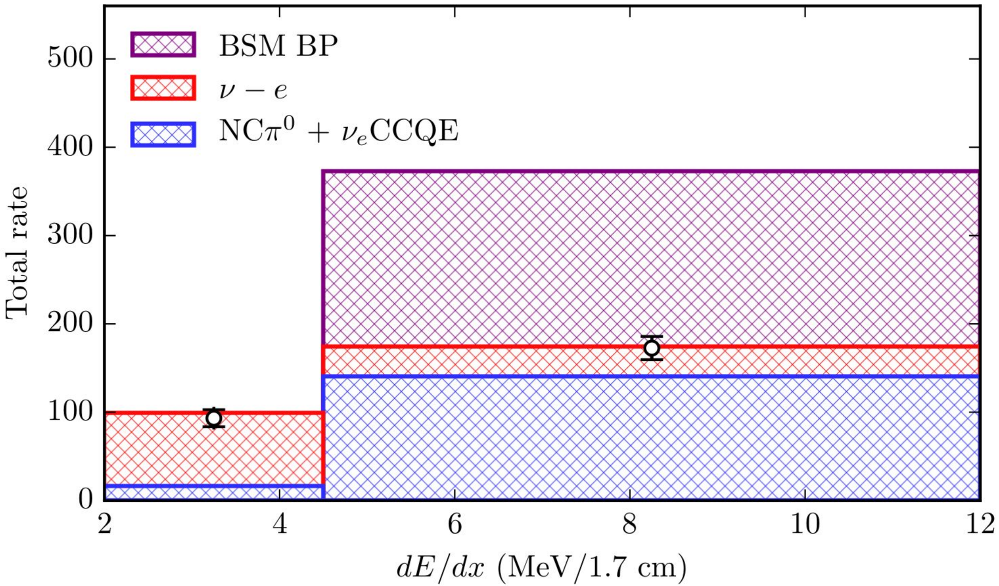
- We set \sigma_\alpha = 10 % account for beam uncertainties.
- We set \sigma_\beta = 30% motivated by the amount of tuning; conservative with respect to tune normalization uncertainty.
- We include only coherent contribution to the BSM signal to avoid hadronic activity cuts.

MINERvA: Our Analysis setup

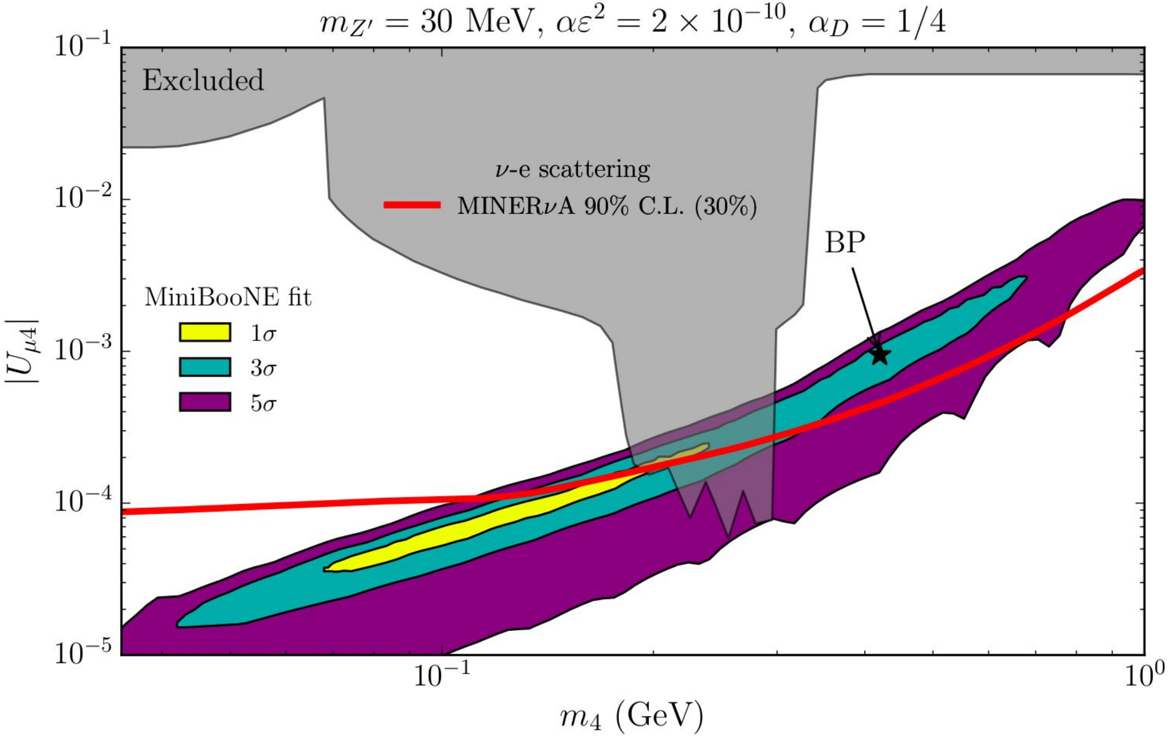
- We do a rate-only analysis on the single bin with

dE/dX > 4.5MeV/(1.7cm)

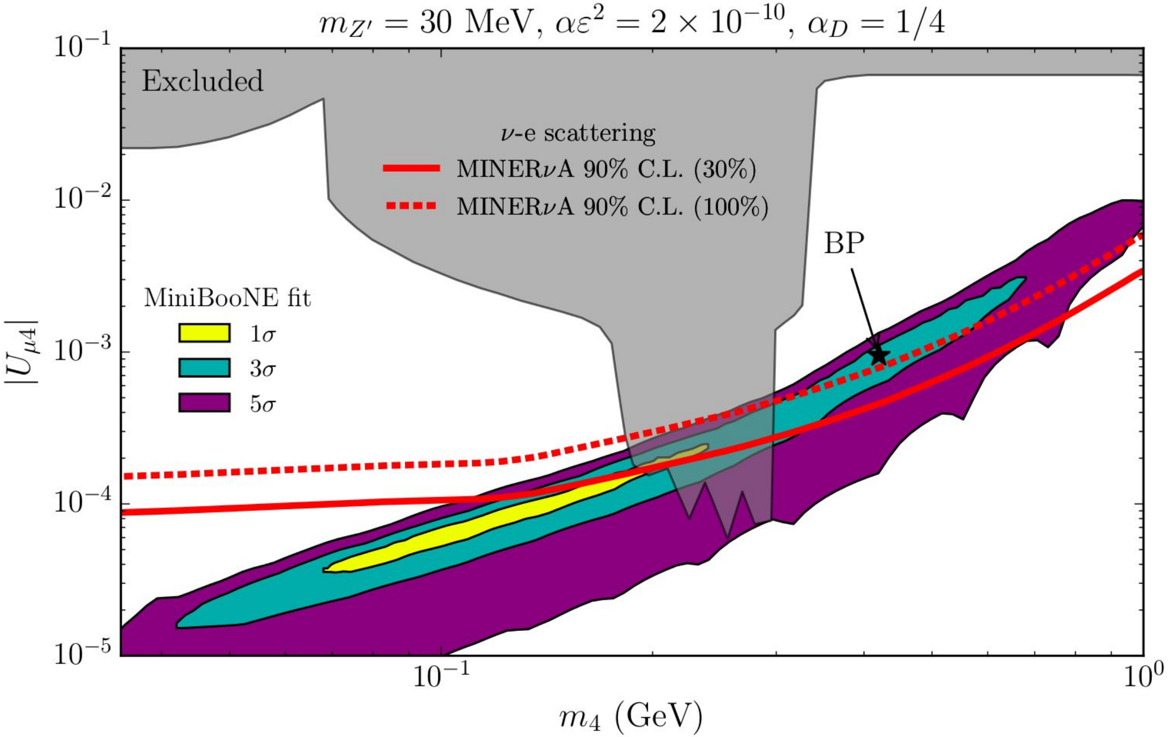
- We use 3.43e20 POTs, Assume fiducial mass of 6.10 tons.



MINERvA result

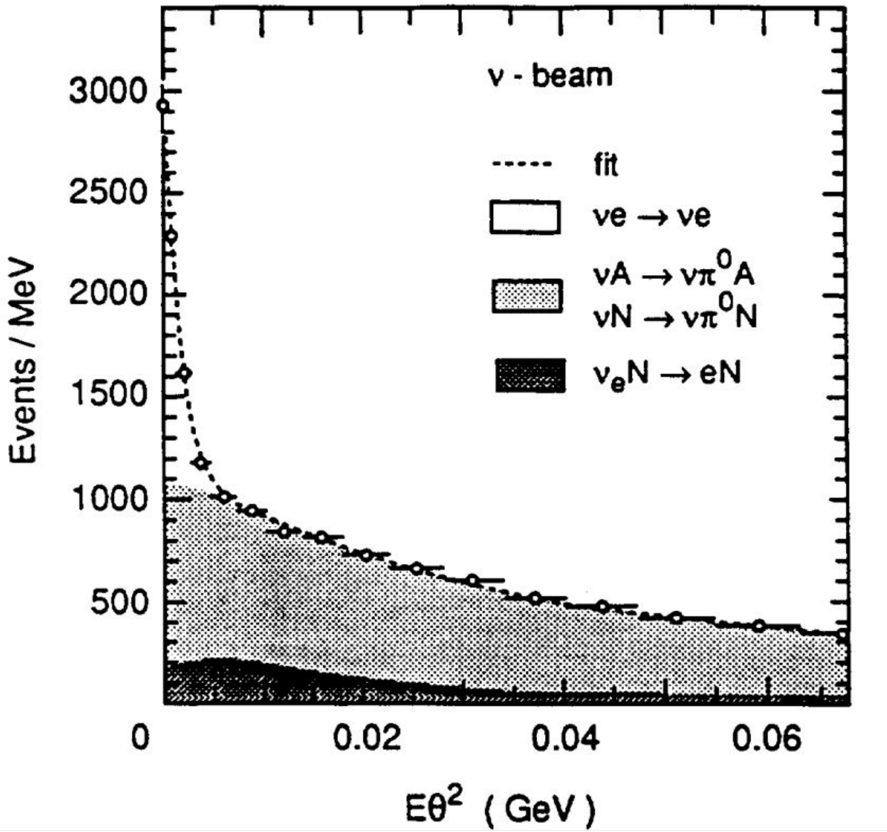


MINERvA result



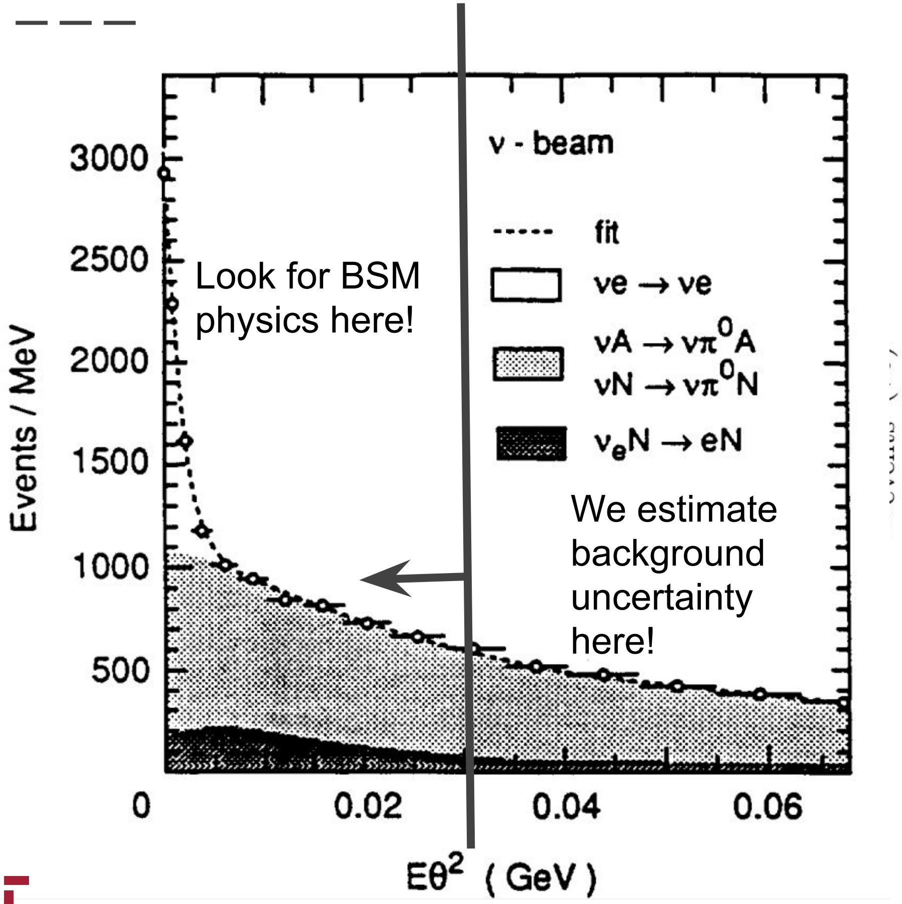
We checked that changing the background uncertainty from 30% to 100% changes the result by no more than a factor of two. The constraint power is coming from the BSM signal overshooting the data.

CHARM-II: complementary measurement

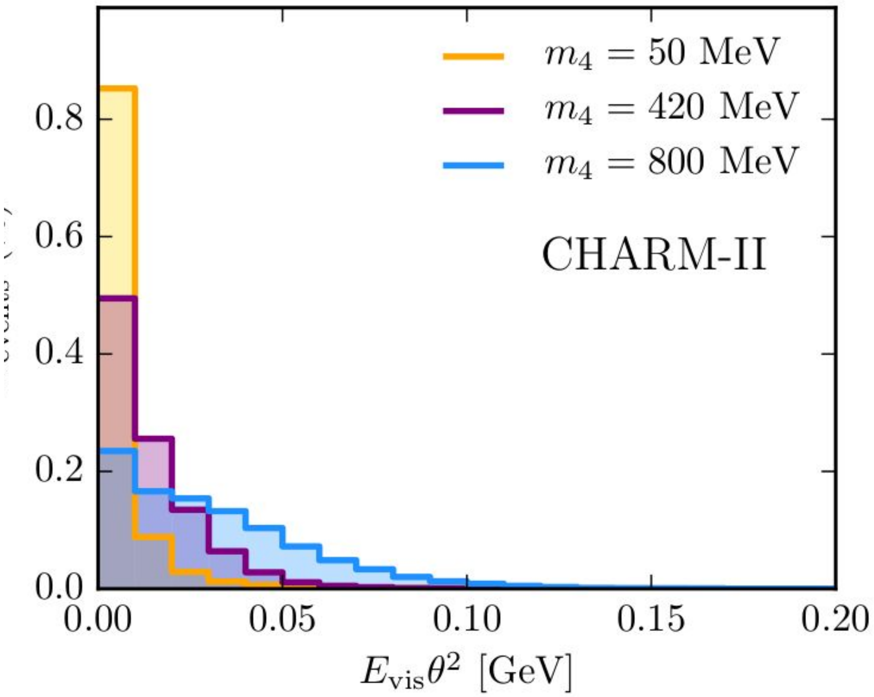


For CHARM-II we are going to use the E\theta^2 distribution before the final dE/dX cut is applied.

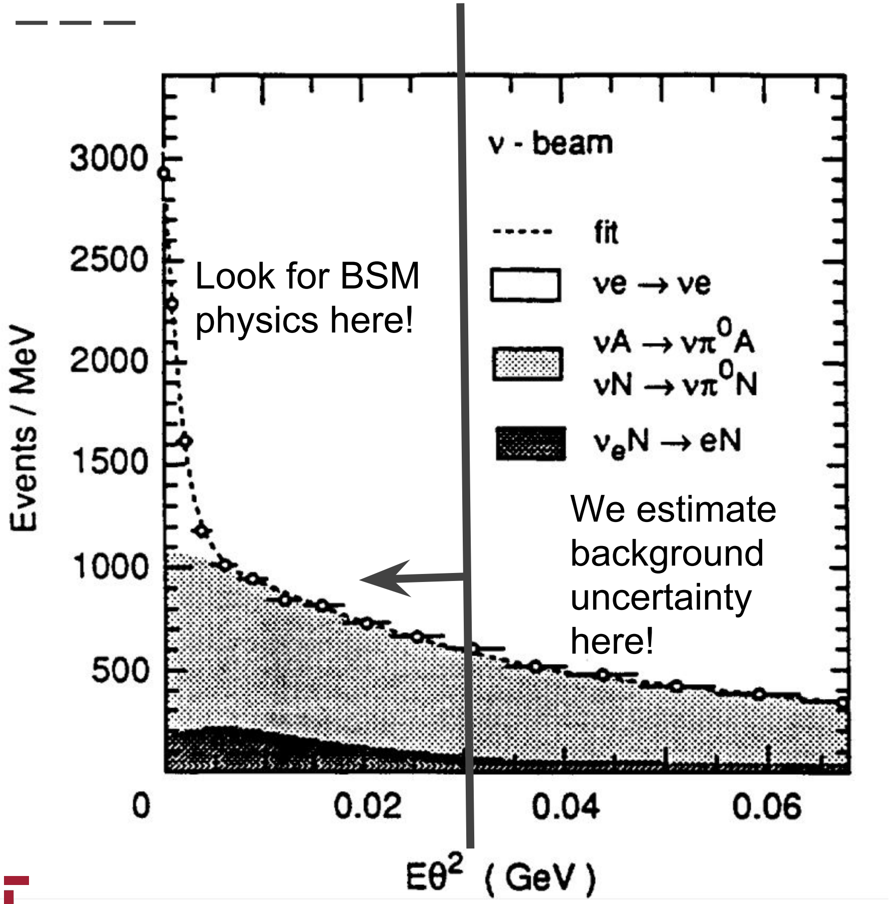
Finding “BSM-safe” sideband to measure background



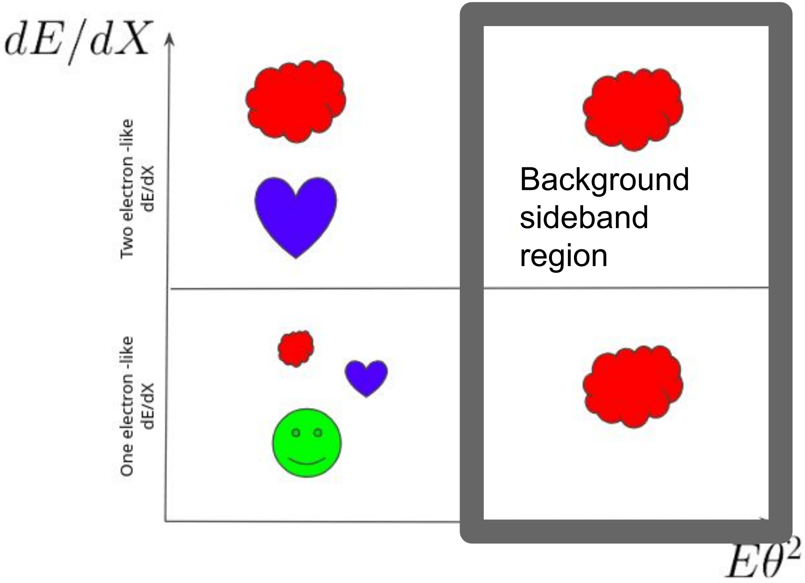
Angular distribution of BSM-signal



CHARM-II: complementary measurement



For CHARM-II we use the distribution before the angular cut and dE/dX were applied

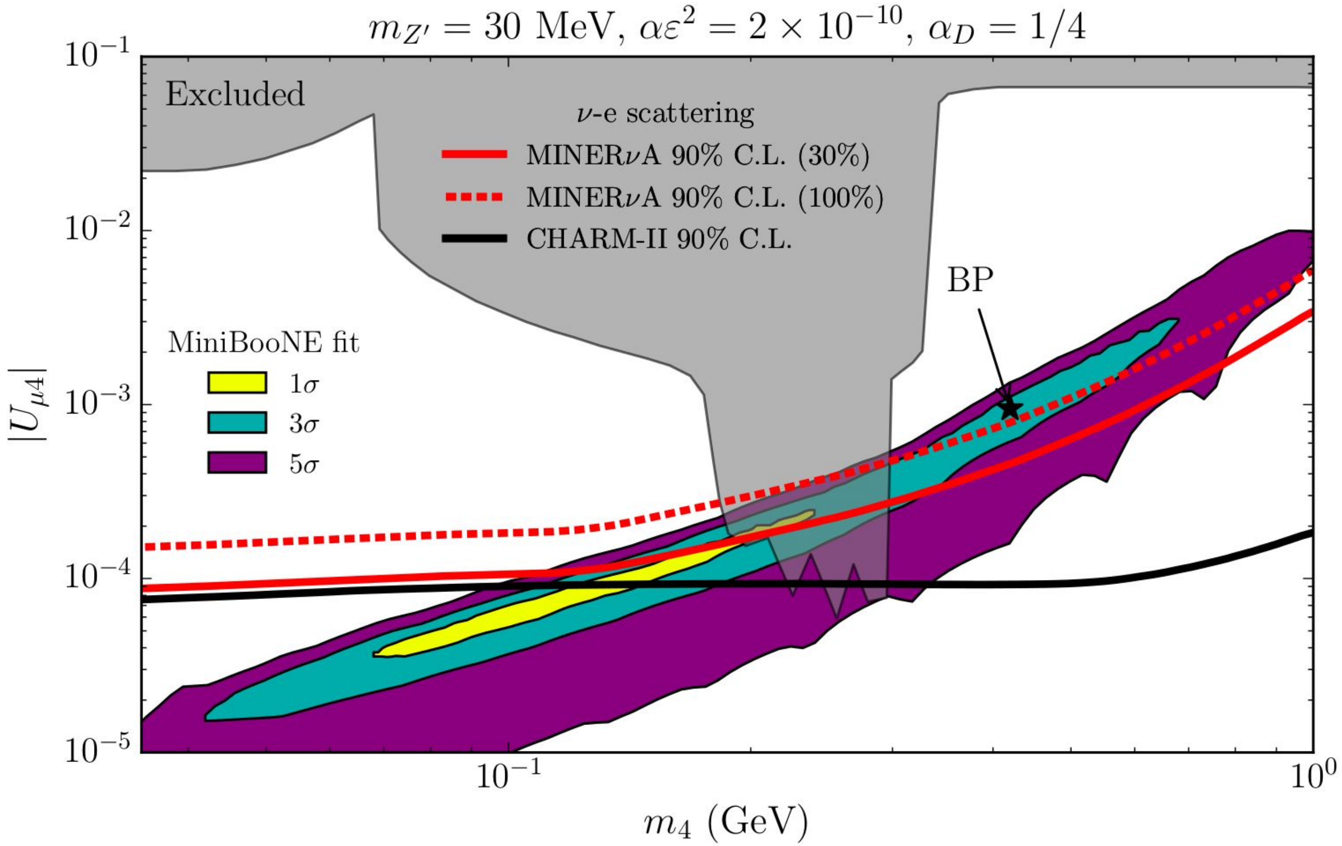


Use the region with E\theta^2>0.03 to obtain the background uncertainty.
Allow for rate/slope to change; with this we estimate its rate to be constrain to be ~3%.

Our CHARM-II analysis setup details

- Rate-only analysis on a single bin with $E\theta^2 < 0.03$ GeV.
- Same χ^2 definition as in MINERvA, but updated uncertainties.
- Background norm. from sideband ~ 3%; flux uncertainty ~ 4%.
- We assume a fiducial mass of 547tons, <A>~20.7, and 2.5e19 POT.

Putting it all together: the money plot



Take home message: lessons learned

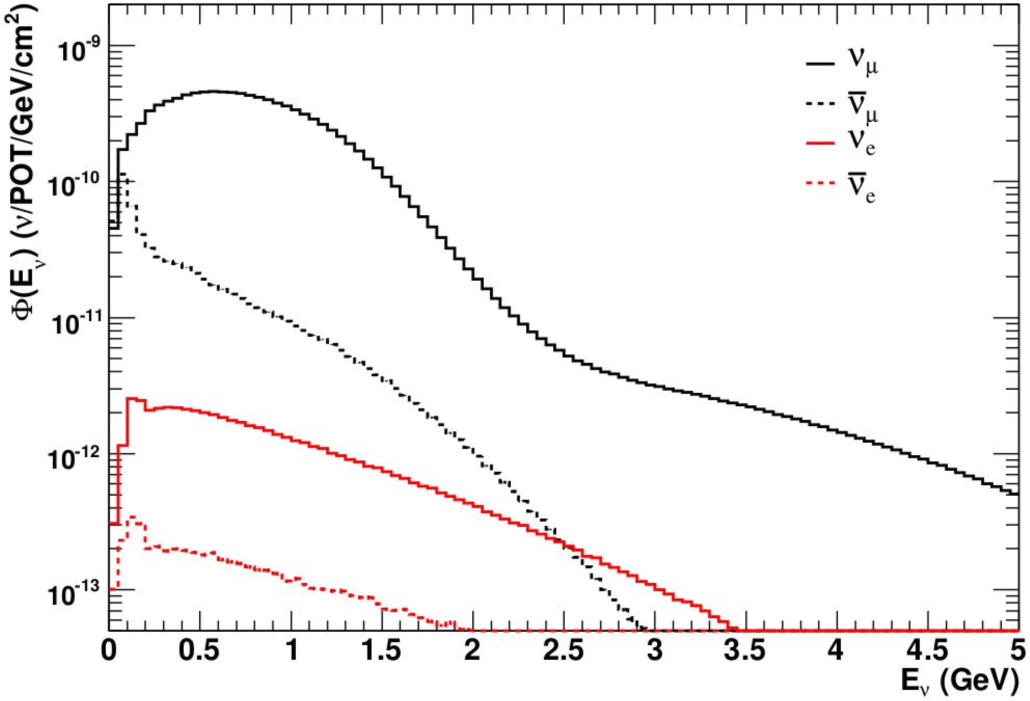
- We are excited to see upcoming analyses by Minerva-ME and NOvA!
- We have used two different experiments to constrain recent MiniBooNE explanations. Tensions are large.

- Signals with small hadronic activity can be studied in conjunction with measurements of neutrino-electron scattering. See also M. Hostert (@PONDD-Tuesday), for similar claim for trident process searches.
- BSM-safe sidebands are critical if we are going to use tuned background predictions.

Keep your eyes on the arXiv:
paper coming this week

Bonus slides!

Booster beam primer

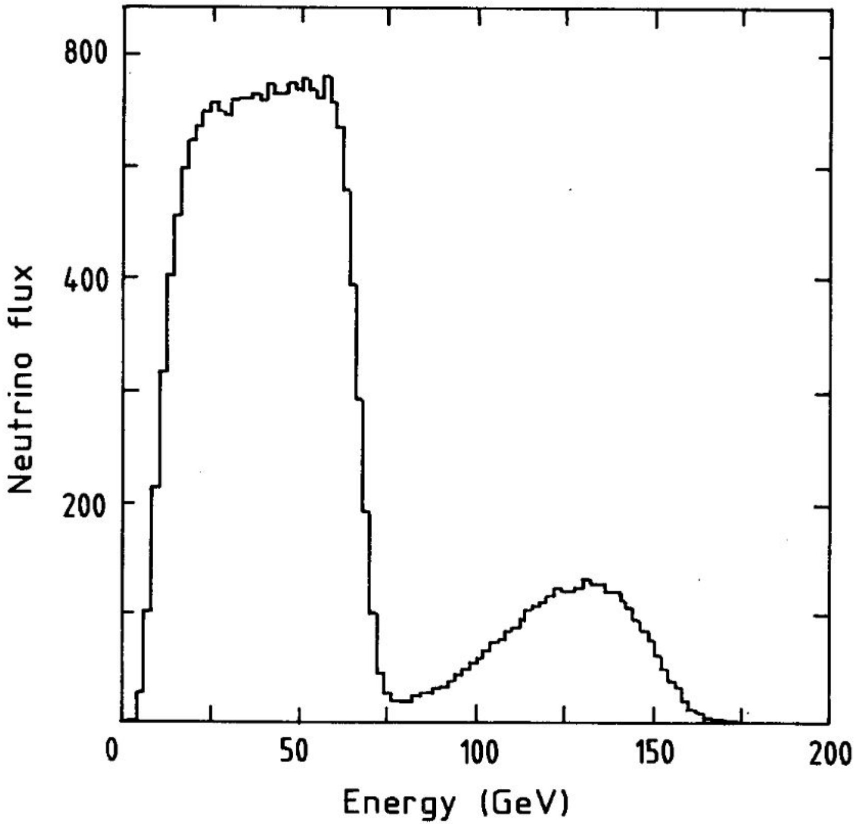


- Maxima < 1 GeV neutrino energy
- Production of heavy states via neutrino interaction: hard.
- Heavier BSM physics look like "effective"-interactions; then angular distribution of excess wont work.

Recent proposals:
Light new physics ~< GeV.

see arXiv:0806.1449

CHARM-ii flux



CHARM-ii flux uncertainties

Systematic uncertainty of total cross-sections

Uncertainty	$\bar{\nu}$ (%)	ν (%)	$\bar{\nu}/\nu$ (%)
Absolute flux calibration (BCT, SSD combined)	2.0	2.0	-
Relative $\bar{\nu}/\nu$ flux	-	1.7	1.7
Dead-time	0.7	0.7	0.5
Target density	1.0	1.0	-
Event number systematic errors	1.7	0.2	1.7
Total systematic error	**2.9**	**2.9**	**2.5**