DUSEL Beam Design: A Tale of Tails

DUSEL Beamline Working Group Mtg, 2/23/09

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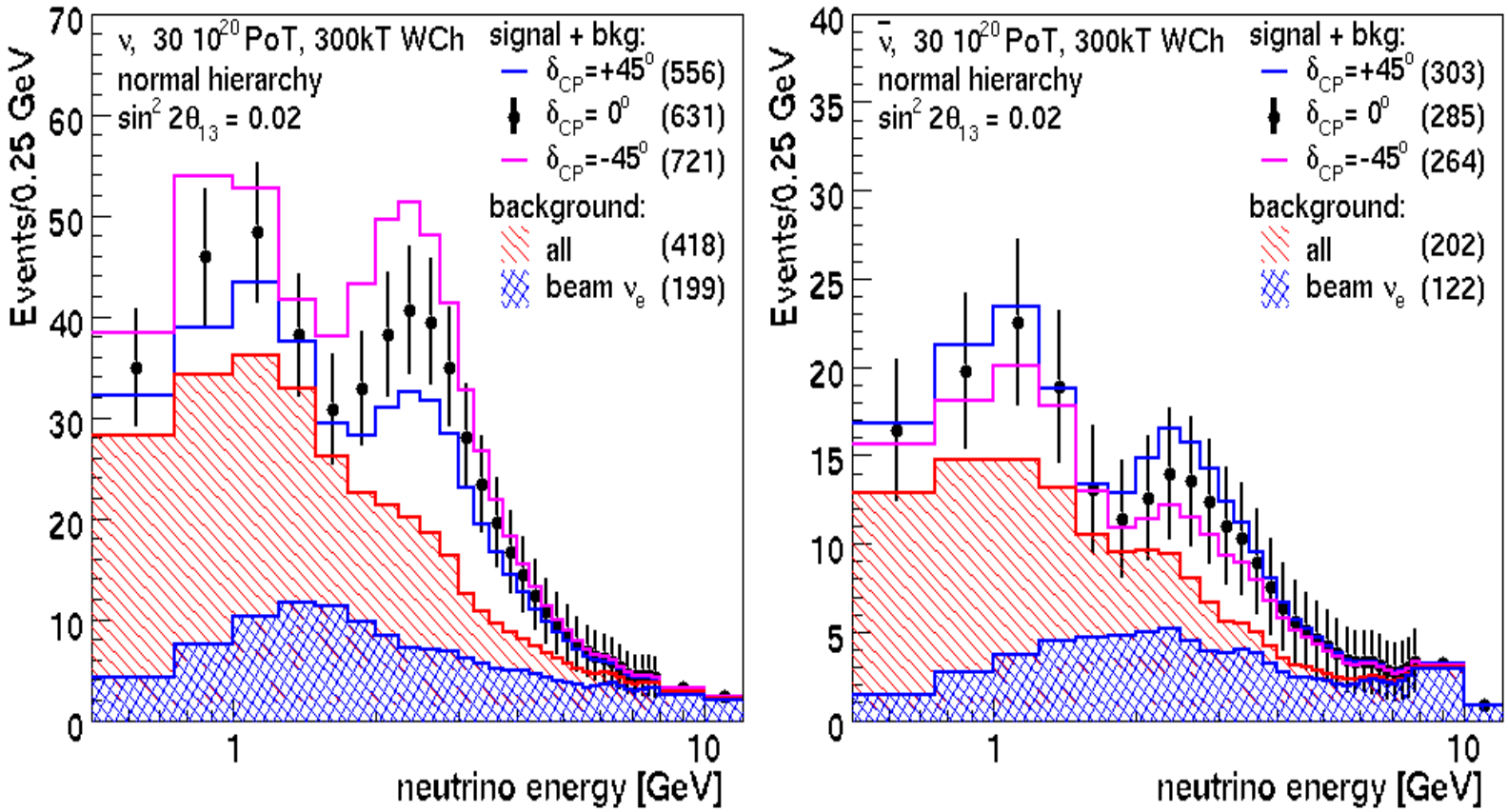
Outline

Backgrounds to $\nu_\mu \longrightarrow \nu_e$ in WCC

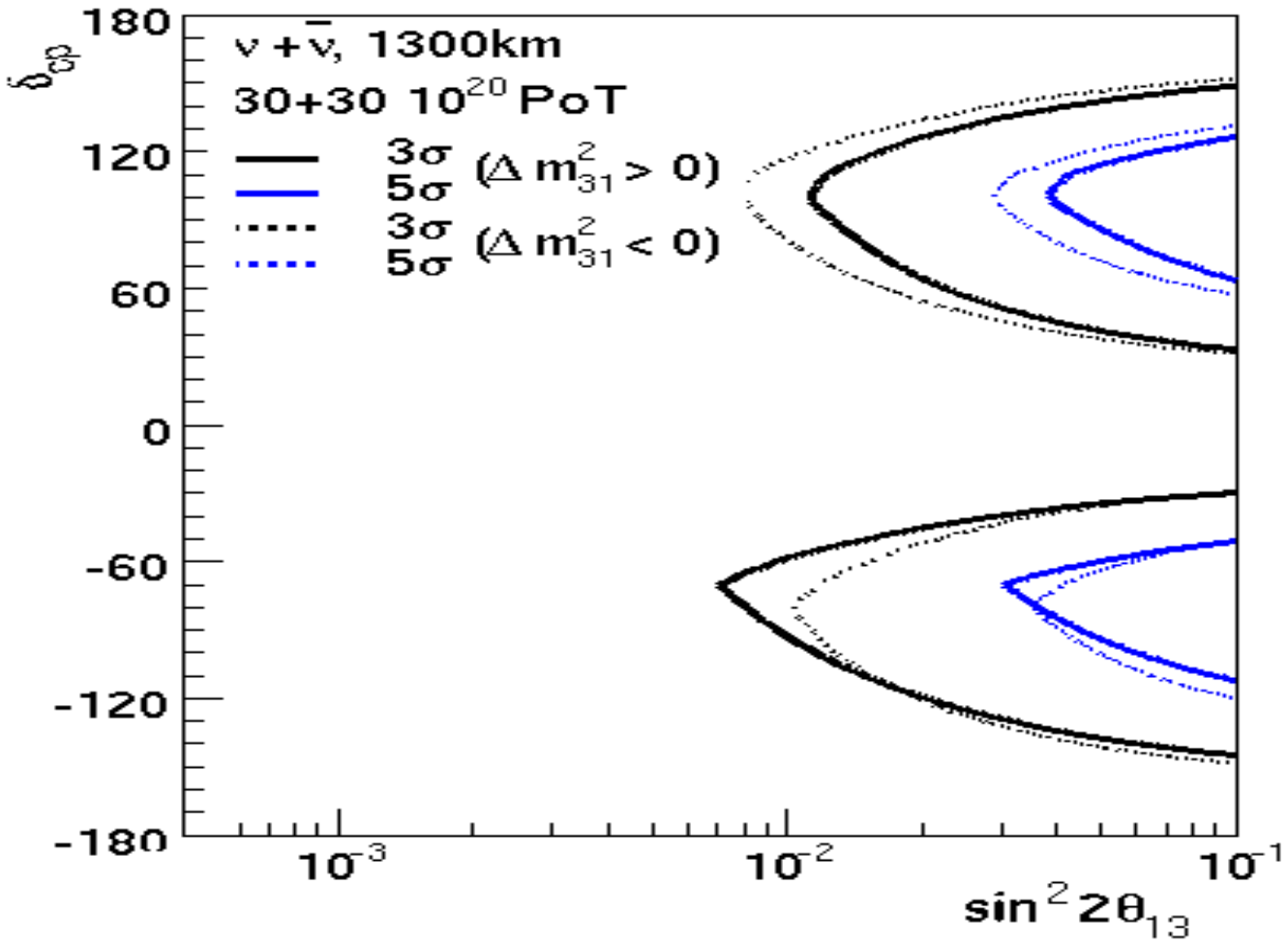
Using a preliminary DUSEL beam and a parameterized simulation based on SuperK response for $\sin^2(2\theta_{13}) = 0.02$ after 3 MW.yr:



NC events dominate the large backgrounds in WCC

CPV sensitivity with smaller backgrounds

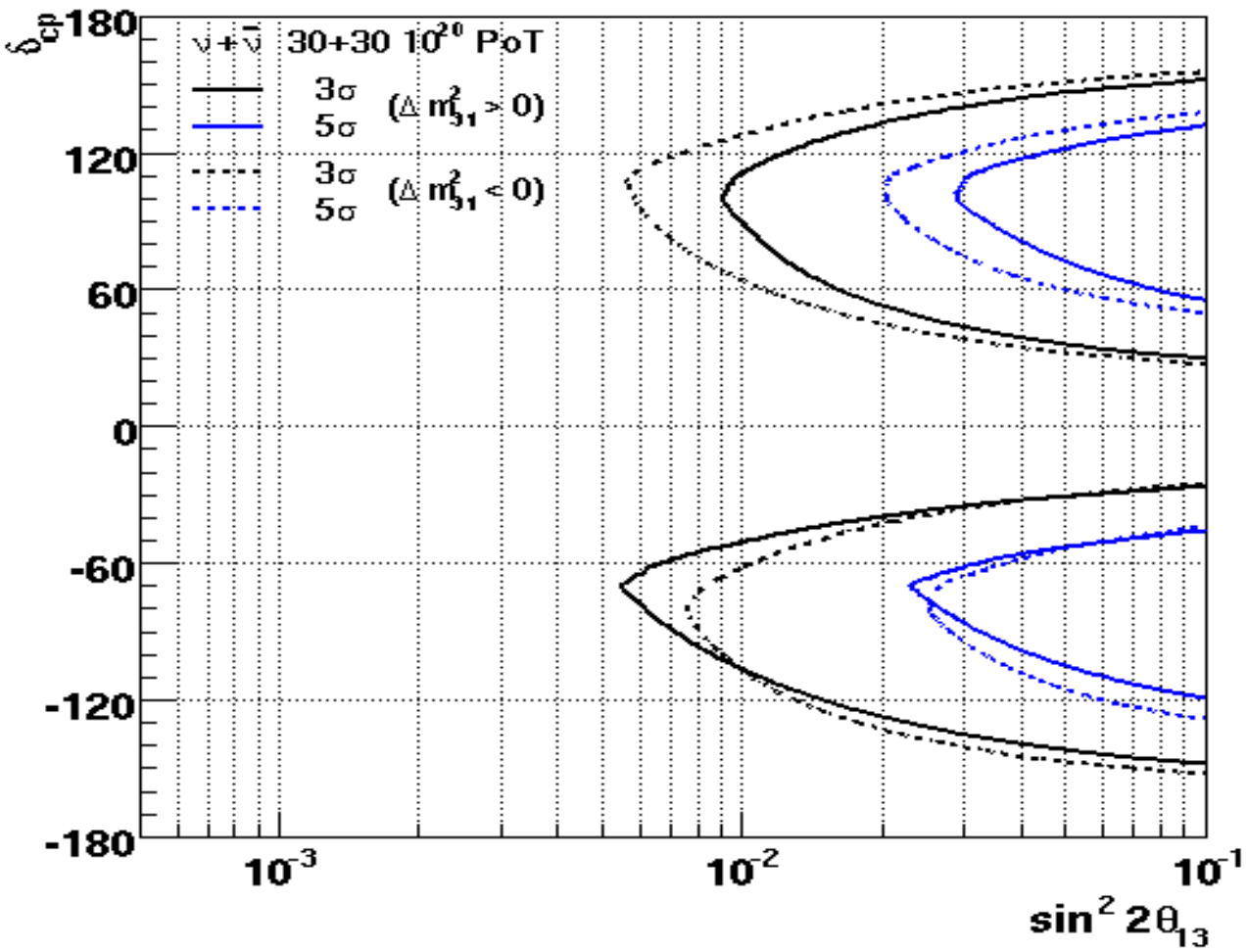
Mark Dierckxsens



Sensitivity with std background, 10% uncertainty

CPV sensitivity with smaller backgrounds

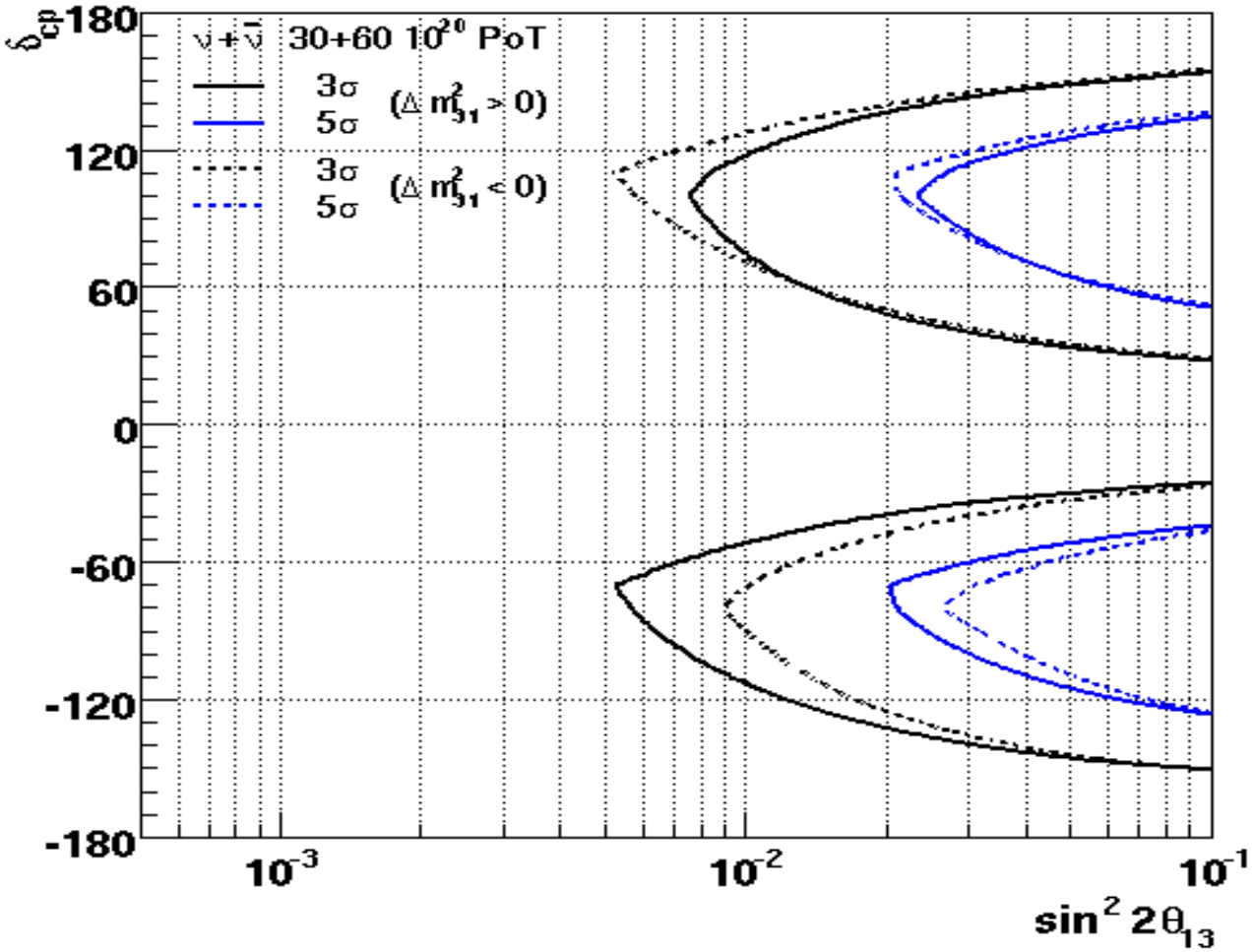
Mark Dierckxsens



Sensitivity with 1/2 background, 10% uncertainty

CPV sensitivity with smaller backgrounds

Mark Dierckxsens



Sensitivity with default background, 10% uncertainty, double $\bar{\nu}$ exposure

CPV sensitivity with smaller backgrounds

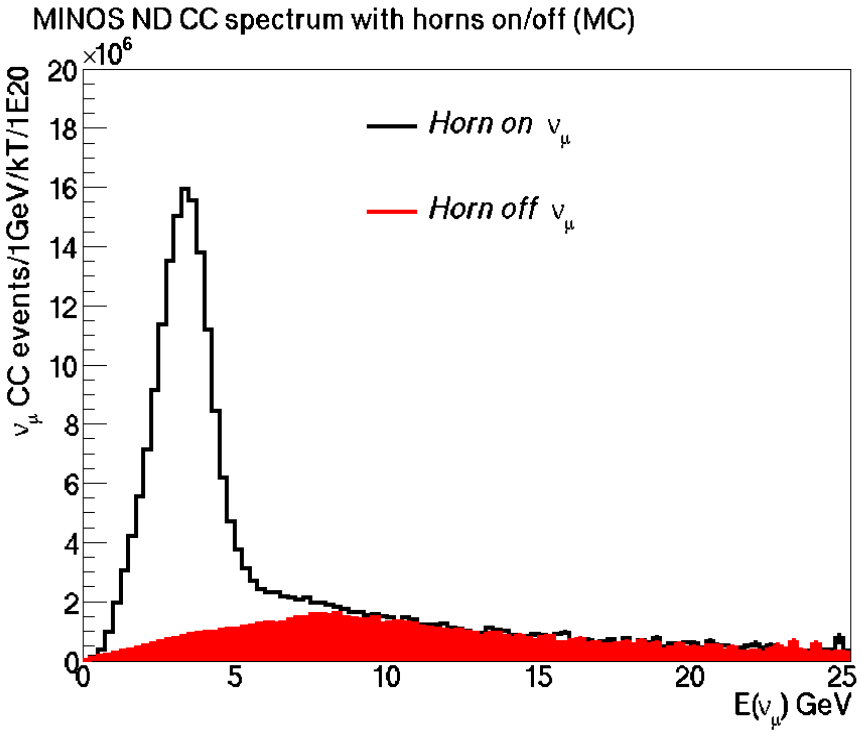
Mark Dierckxsens

For CPV sensitivity

1/2 background $\sim \bar{\nu}$ exposure $\times 2 \equiv$ 3 MW.yrs

Lessons learned from MINOS

NC backgrounds in the MINOS ND Data

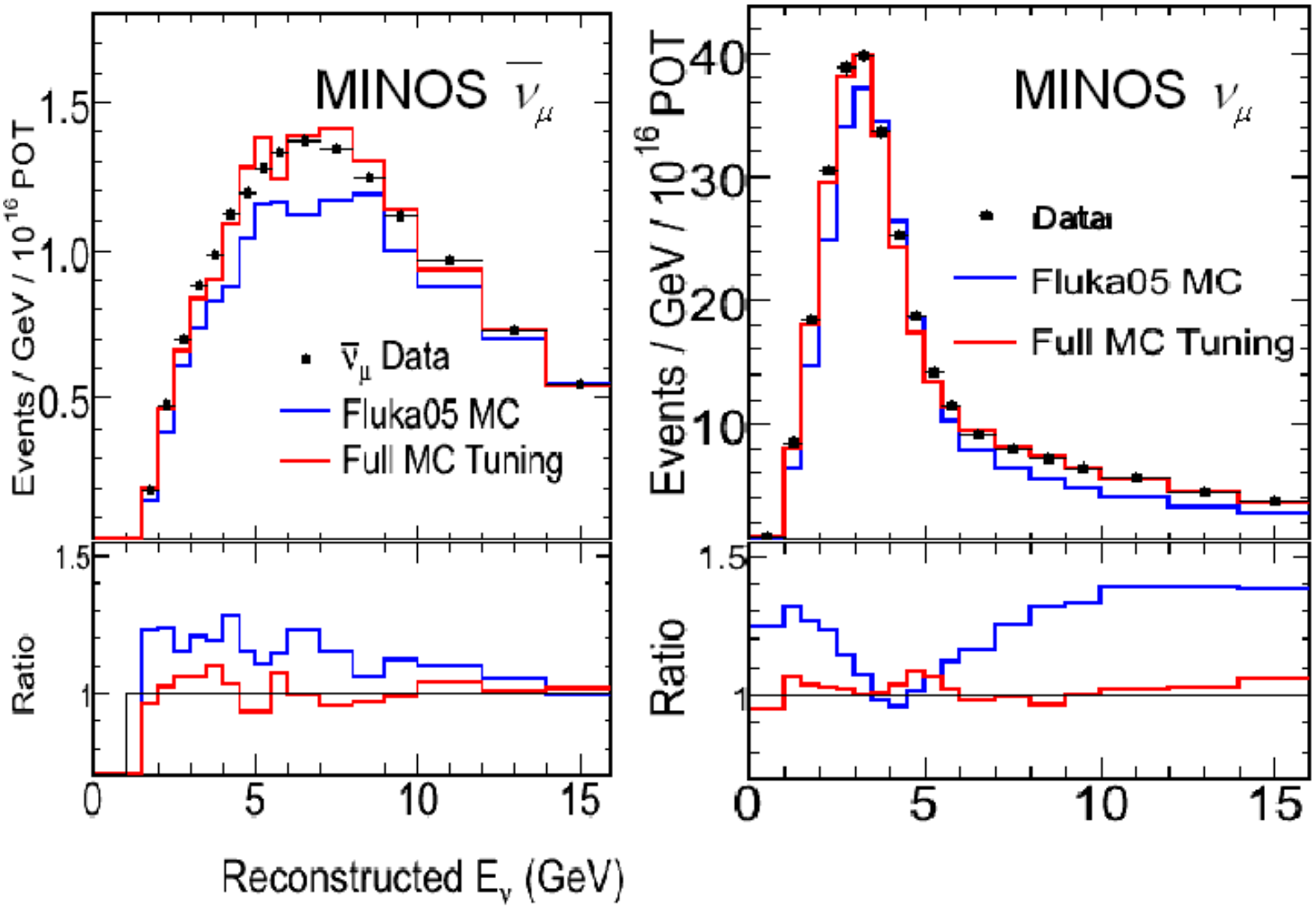


In the MINOS ND data we measured the background composition of ν_e selected events with horn on/off in the region 1-8 GeV.

SEE MAYLY's TALK NEXT WEEK.

$$\frac{\text{NC from tails}}{\text{All NC}} \sim \frac{\text{NC horn off}}{\text{NC horn on}} \sim 0.5 - 0.6$$

MINOS measurement of HE tails

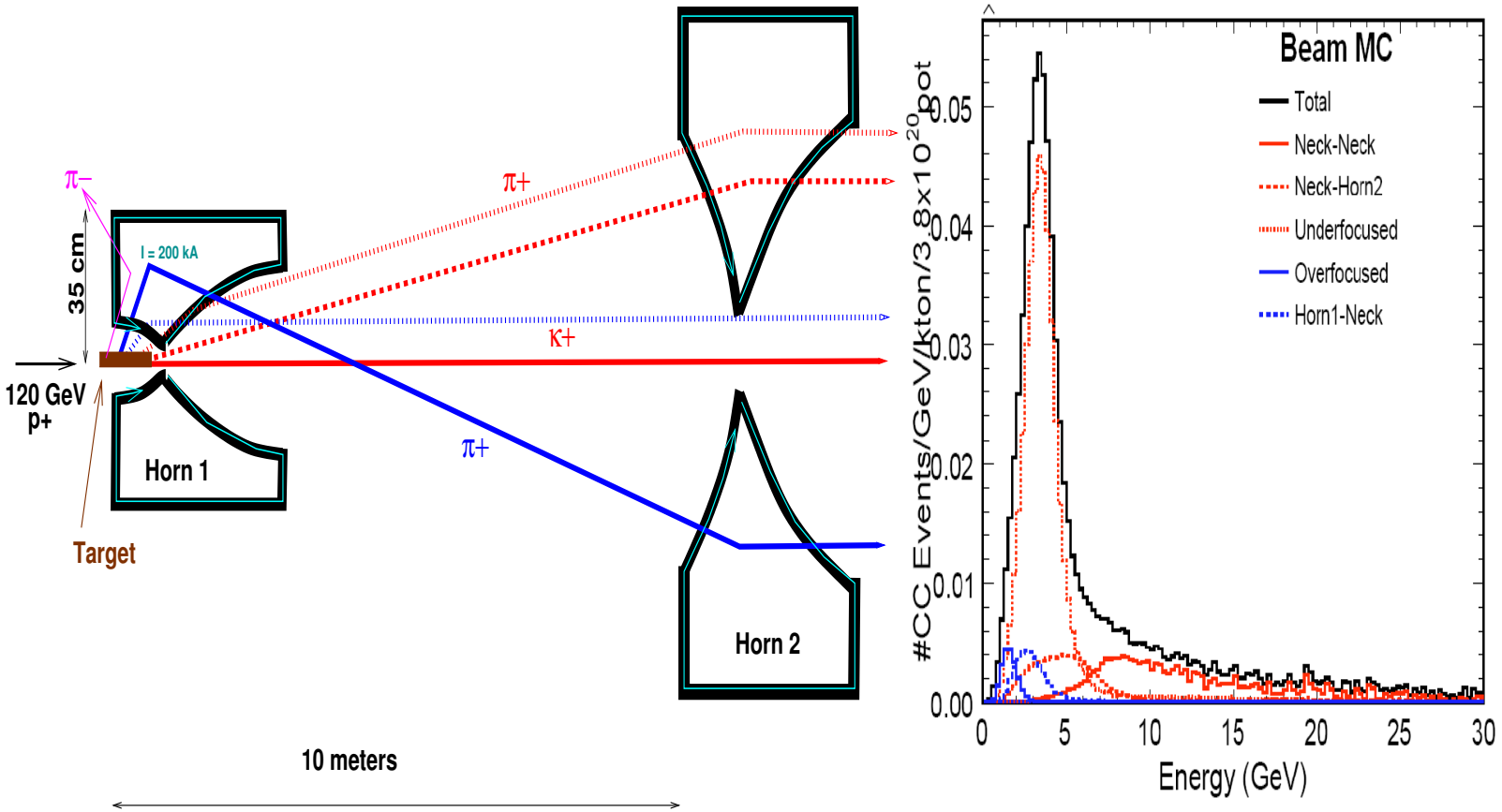


MINOS data 20% more HE νs compared to Fluka05 MC

Reducing the DUSEL beam high energy tails

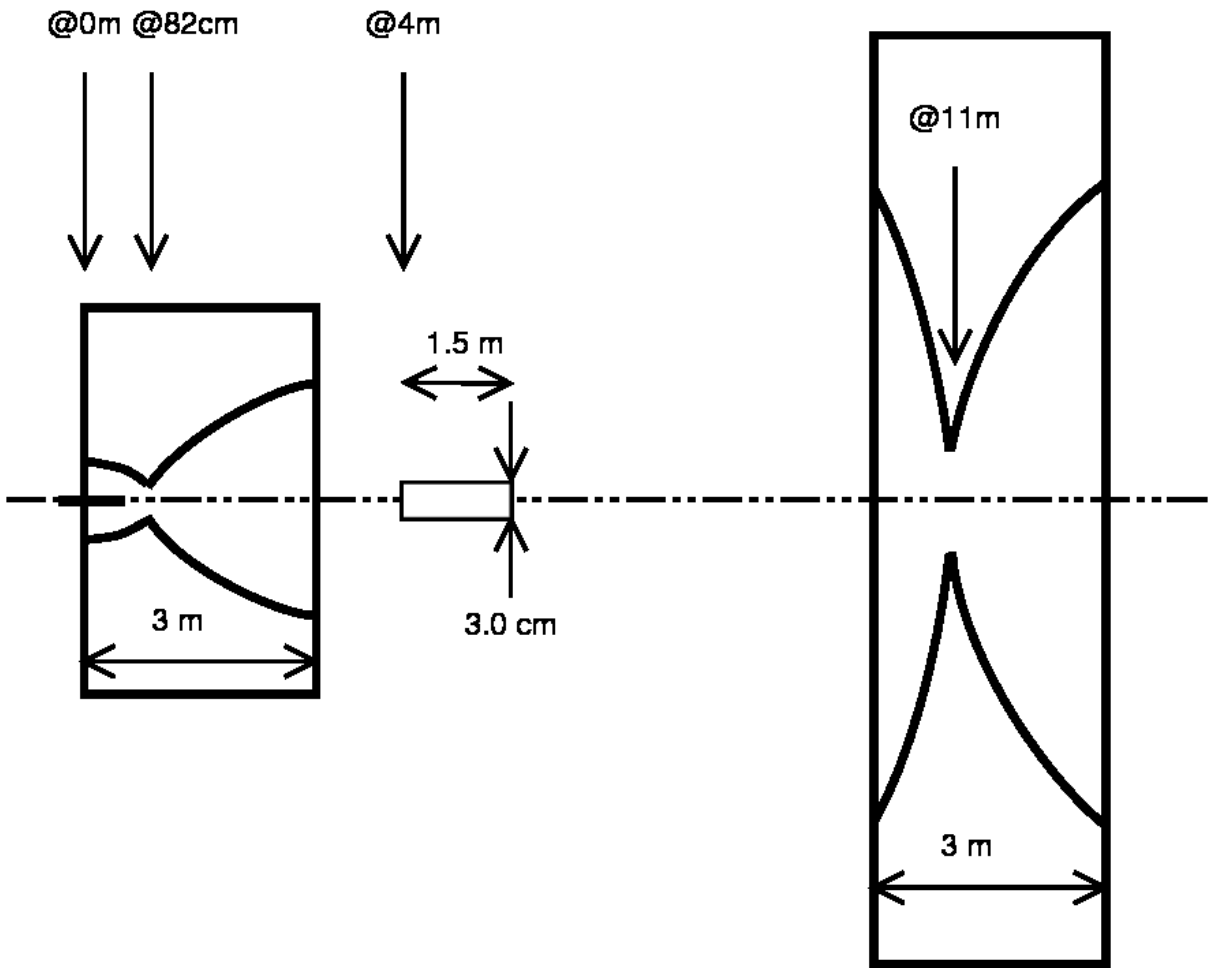
Breakdown of NuMI spectrum

Zarko Pavlovich



High energy ν come from hadrons exiting horn 1 on-axis

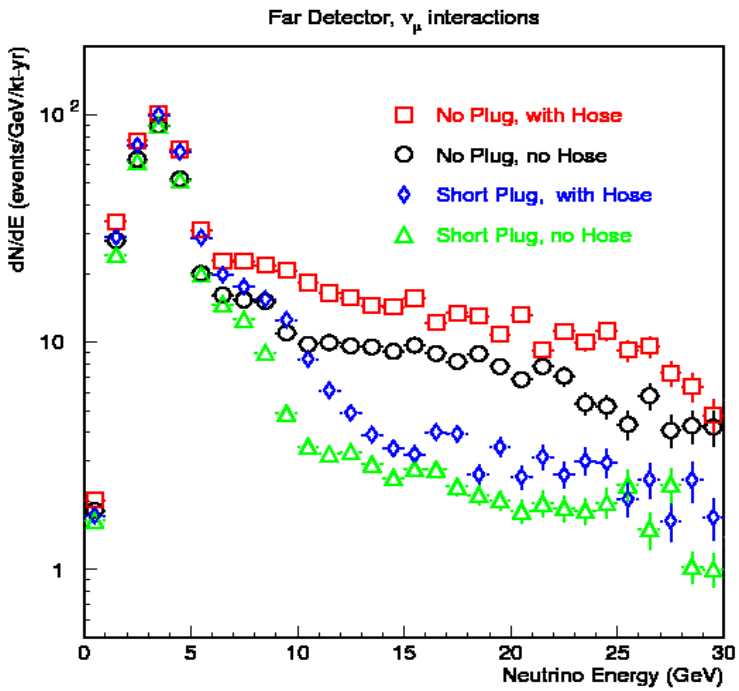
Whats a beam "plug"?

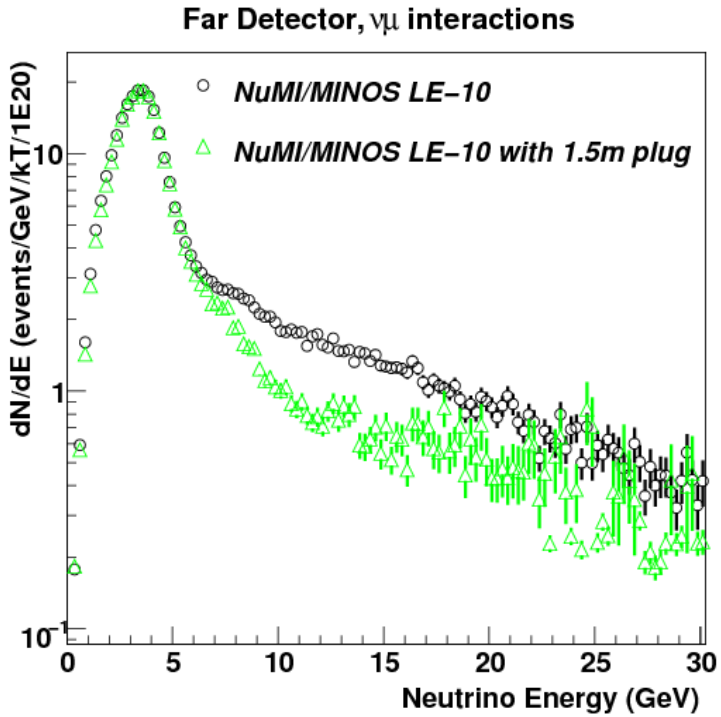


In 2001, Brett Viren (following up on studies at IHEP) found that a 1.5cm radius graphite target placed between the 2 horns reduced the high energy tails in NuMI LE beam by $>$ 30 %.

MINOS LE Simulations with plugs

NuMI/MINOS LE FD spectra with baseline plug:





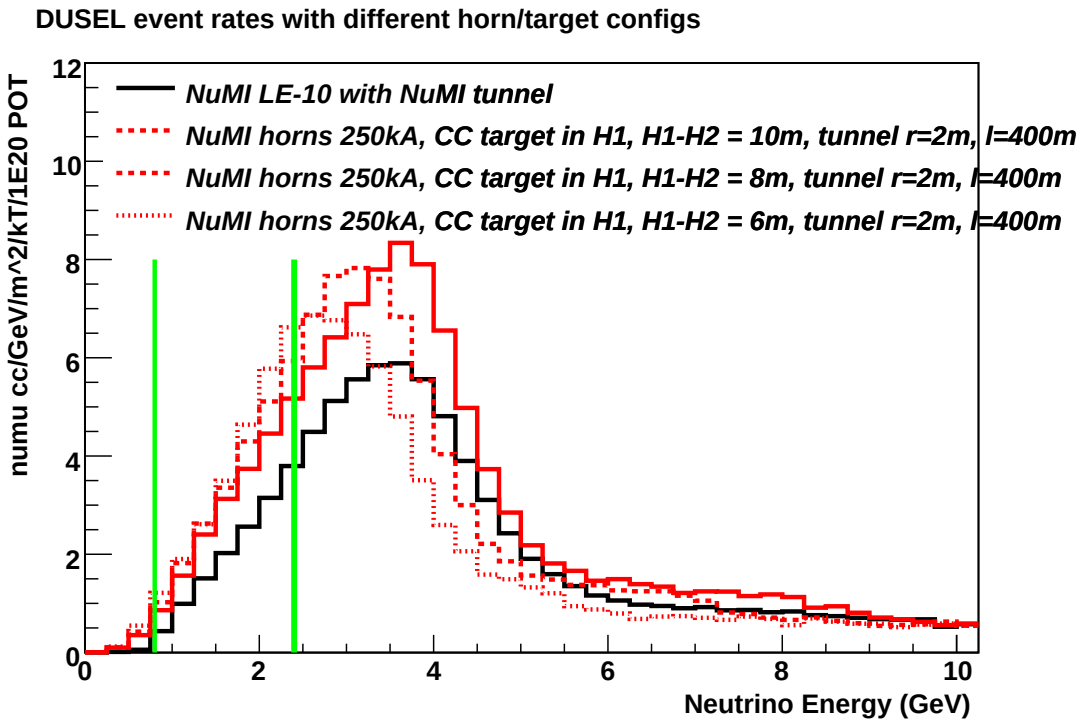
Brett 2001 **Mary 2009**

Change in the spectrum when plug is added is

MC	0-3 GeV	3-6 GeV	6-10 GeV	10-50 GeV
Brett 2001	-7.6%	-2.5%	-26%	-70%
Mary 2009	-4.4%	-1.0%	-23%	-39%

The new DUSEL spectra with NuMI horns

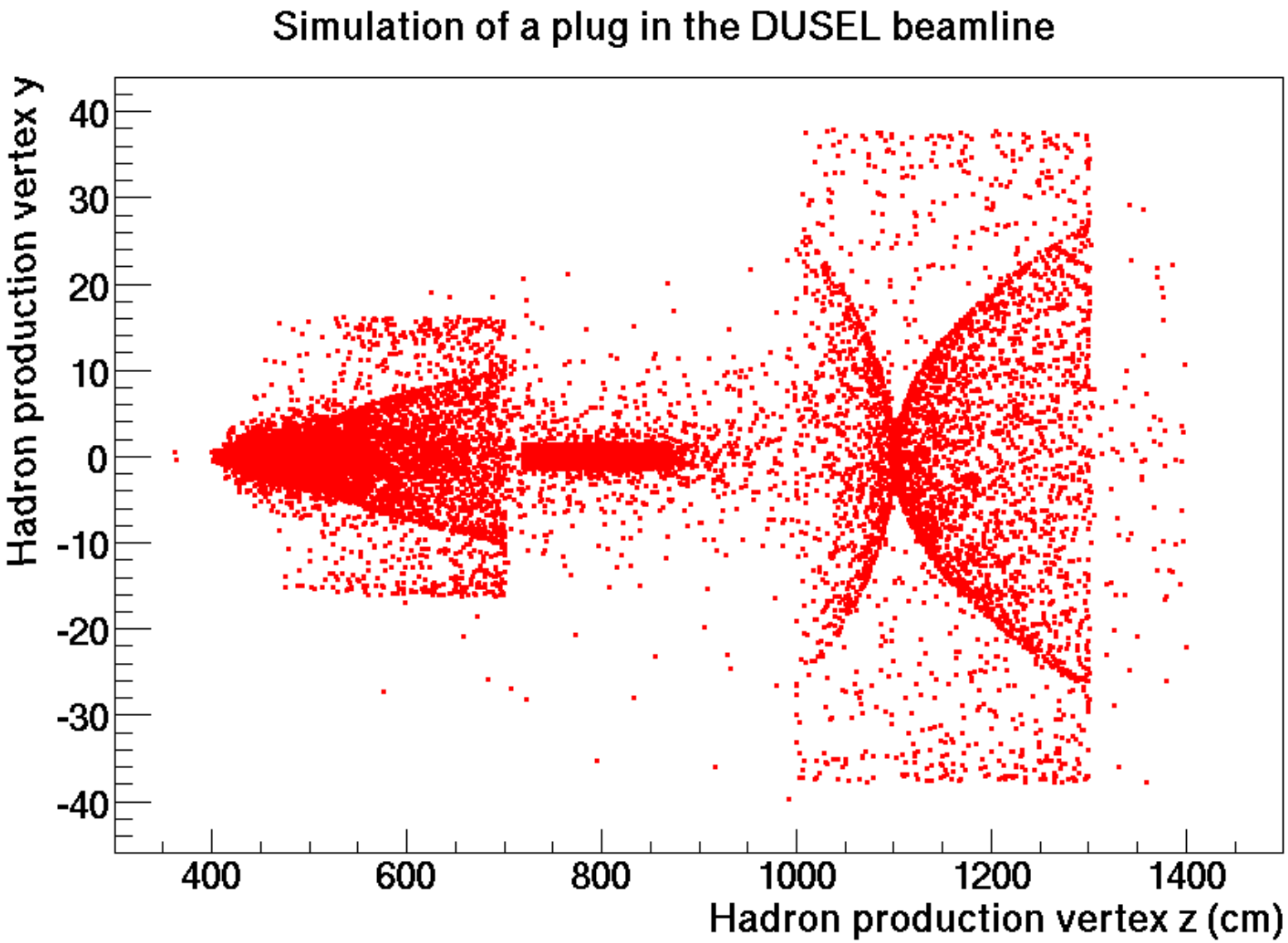
Embed target and decrease separation between Horn1 and Horn2.
I = 250*kA. Decay pipe is 380m long and 4m wide.*



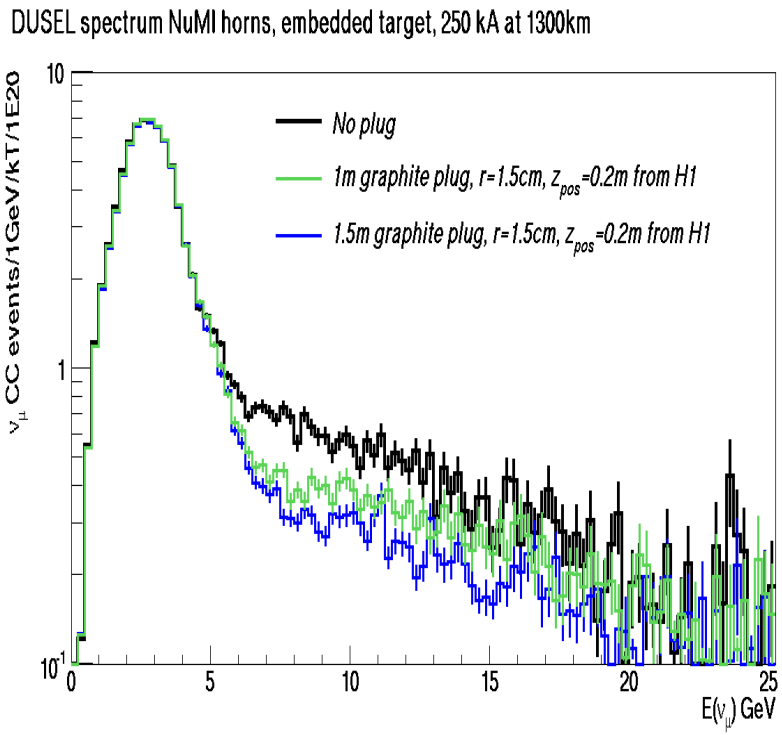
New low energy wide-band on-axis design

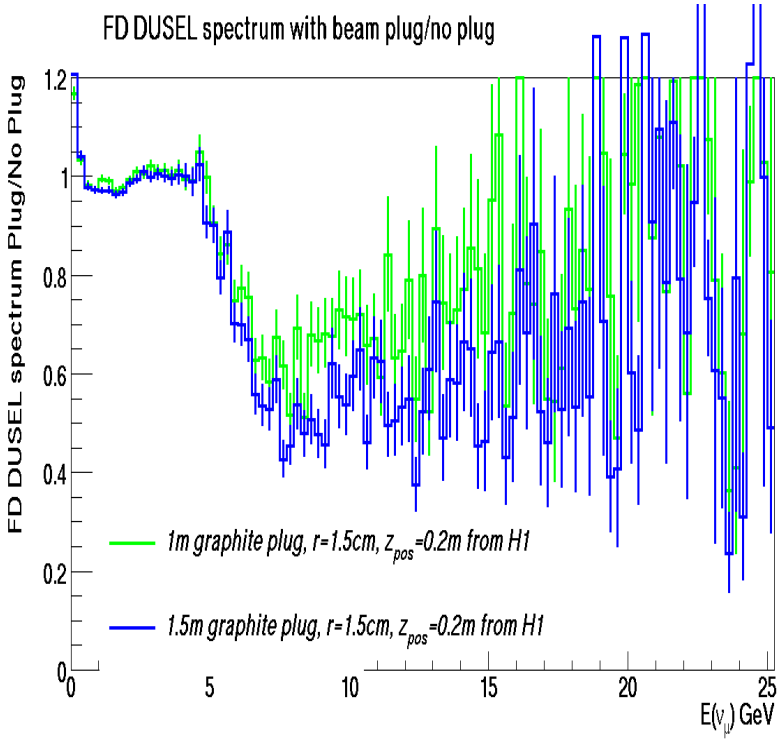
is better suited to DUSEL physics.

Adding plugs to NuMI/DUSEL



DUSEL spectra with different plugs

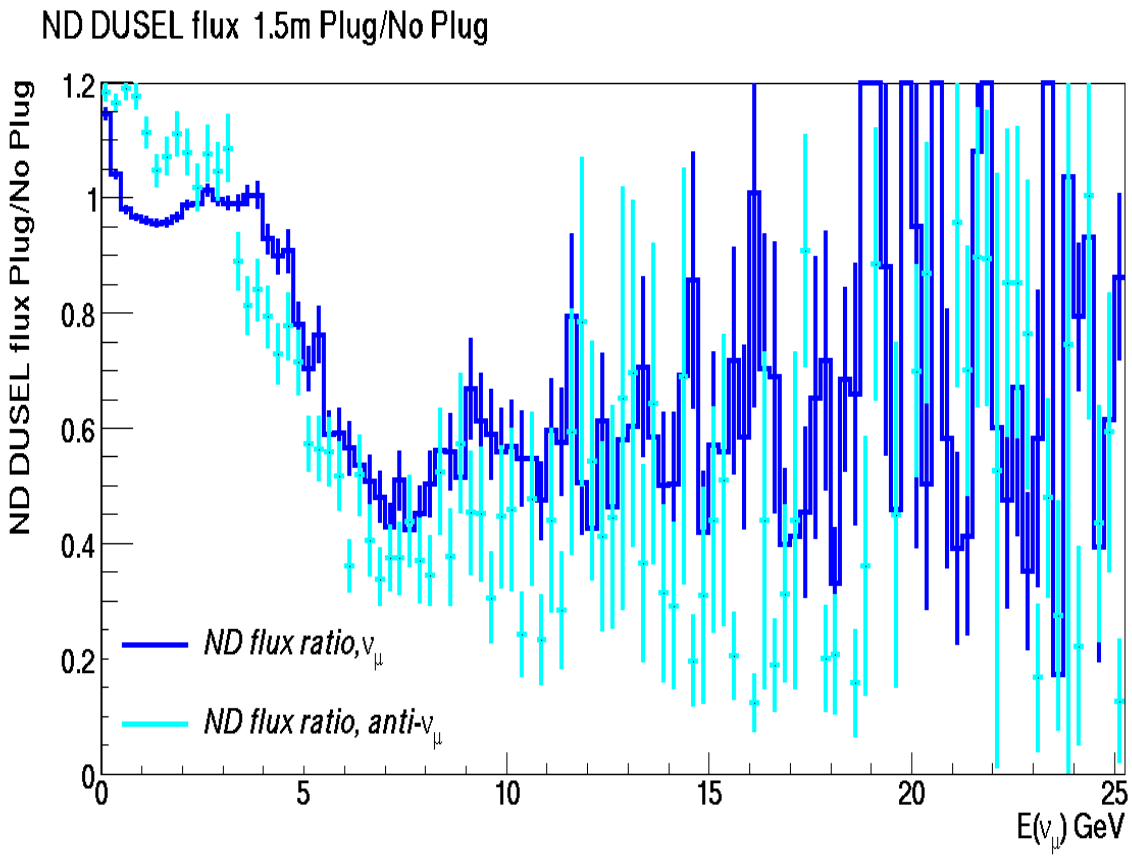




With 1.5m plug

$$\frac{\text{plug}}{\text{no plug}}(> 5\text{GeV}) = 0.62 \qquad \frac{\text{plug}}{\text{no plug}}(< 5\text{GeV}) = 0.99$$

Enhanced production of $\bar{\nu}, \nu_e$ with plug



$\bar{\nu}$ contamination in the ν beam < 3 GeV increases by 10%

$\nu_e + \bar{\nu}_e$ contamination in the ν beam < 5 GeV increases by 6%

Beam plugs Pros and Cons

Pros:

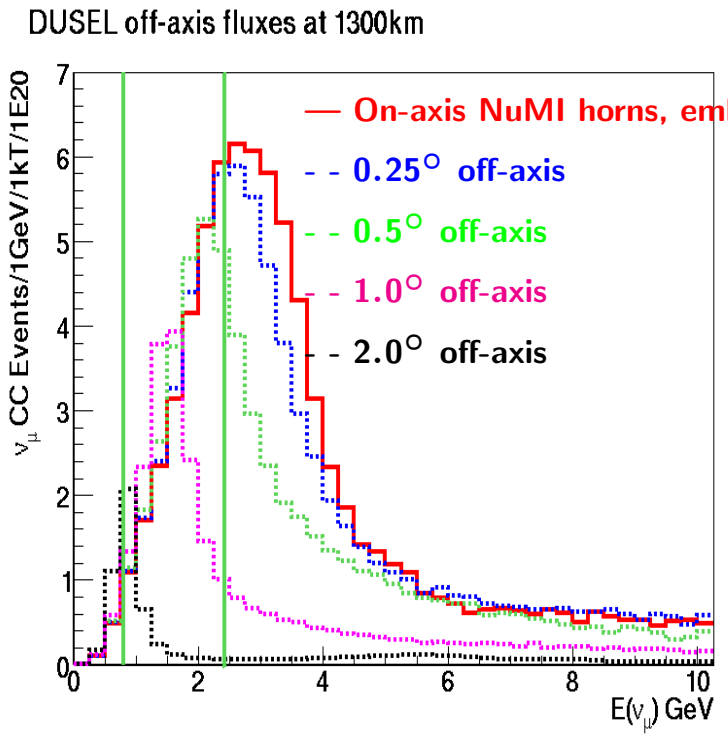
- **Most effective tool that reduces the HE flux exactly where you need it $>$ 5 GeV without any impact at low energy.**
- **Might give you more ν at very low energies $<$ 0.5 GeV - good for solar oscillations.**
- **Tunable - different plugs can be used.**

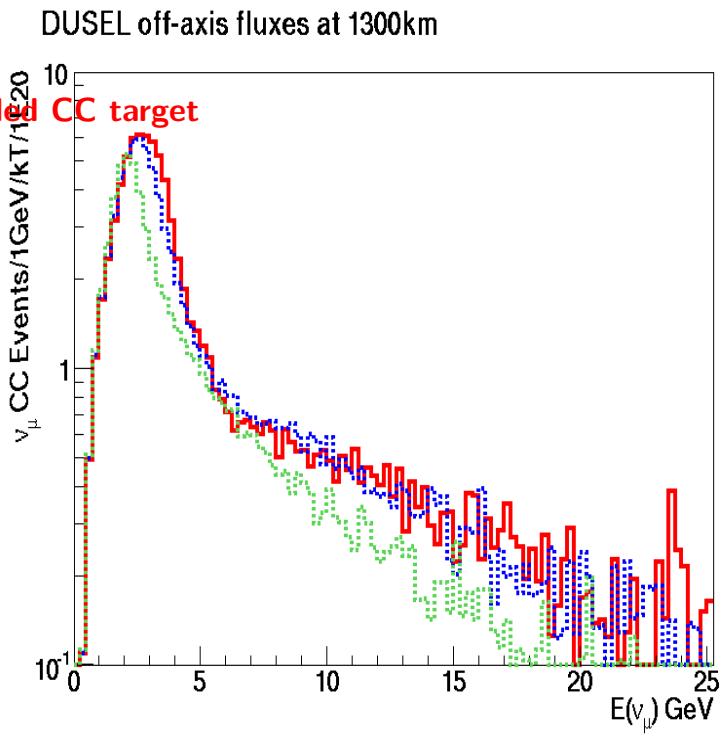
Cons:

- **Requires expensive material R&D and engineering**
- **Complicates operating - need to change out plugs.**
- **Complicates beamline geometry for Near-Far extrapolation**

Going off-axis

Another alternative to cutting down the high energy tails is going off-axis - redo calculation with optimized on-axis beam:



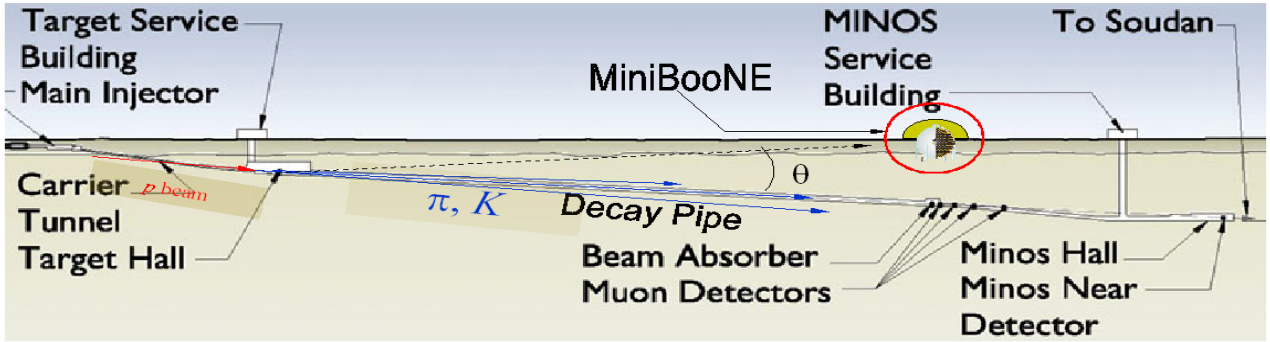


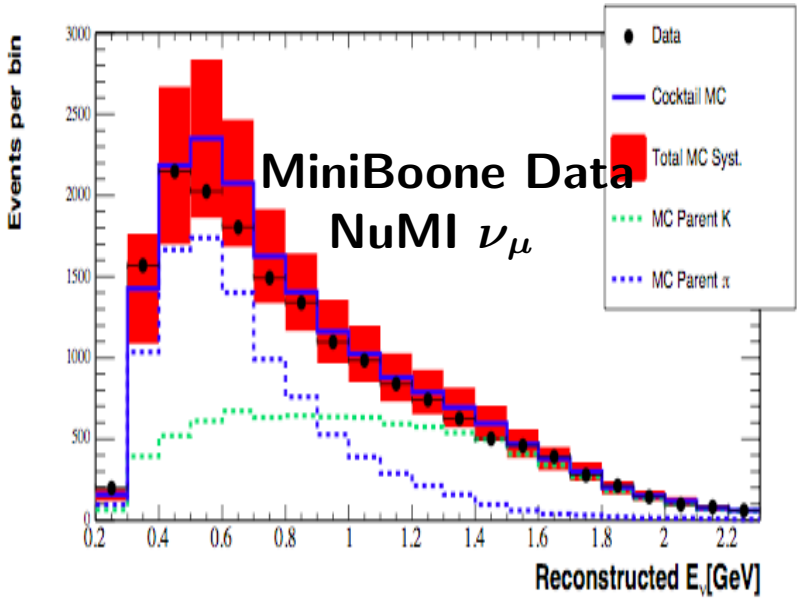
On axis flux is best for broad-band coverage

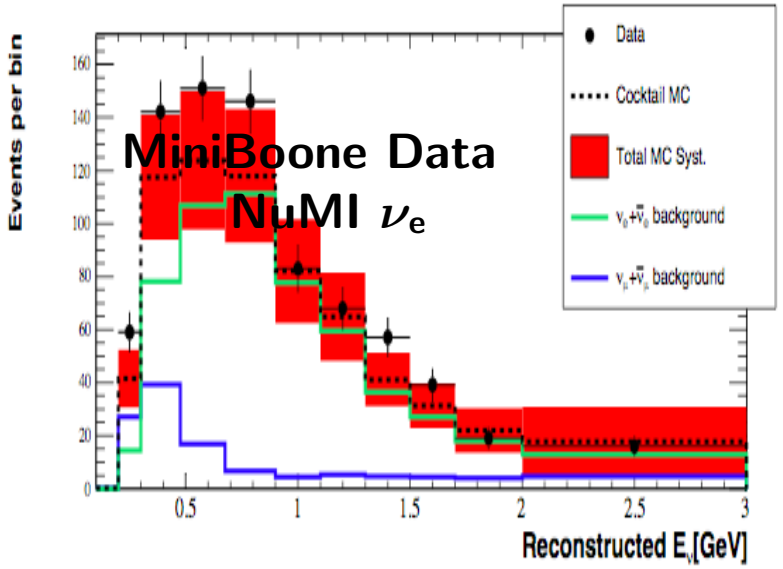
Measurement of NuMI off-axis with MiniBoone

Zelimir Djurcic

The MiniBoone detector is located at an angle of 110mrad off-axis from the NuMI beam 745m downstream of the NuMI target.







First measurement of an off-axis beam - good agreement with prediction

Off-Axis Pros and Cons

Pros:

- **Effective at reducing HE tails.**
- **At high angles $> 1^{\circ}$ enhances flux at the 2nd oscillation maxima.**
- **NuMI/MiniBoone data confirms simulation predictions off-axis**

Cons:

- **Throwing away beam flux at 1st osc maximum**
- **Limited tunability - WE CANT MOVE THE BEAMLINE!**
- **Limited broad-band spectrum.**

Helium in the Decay Pipe

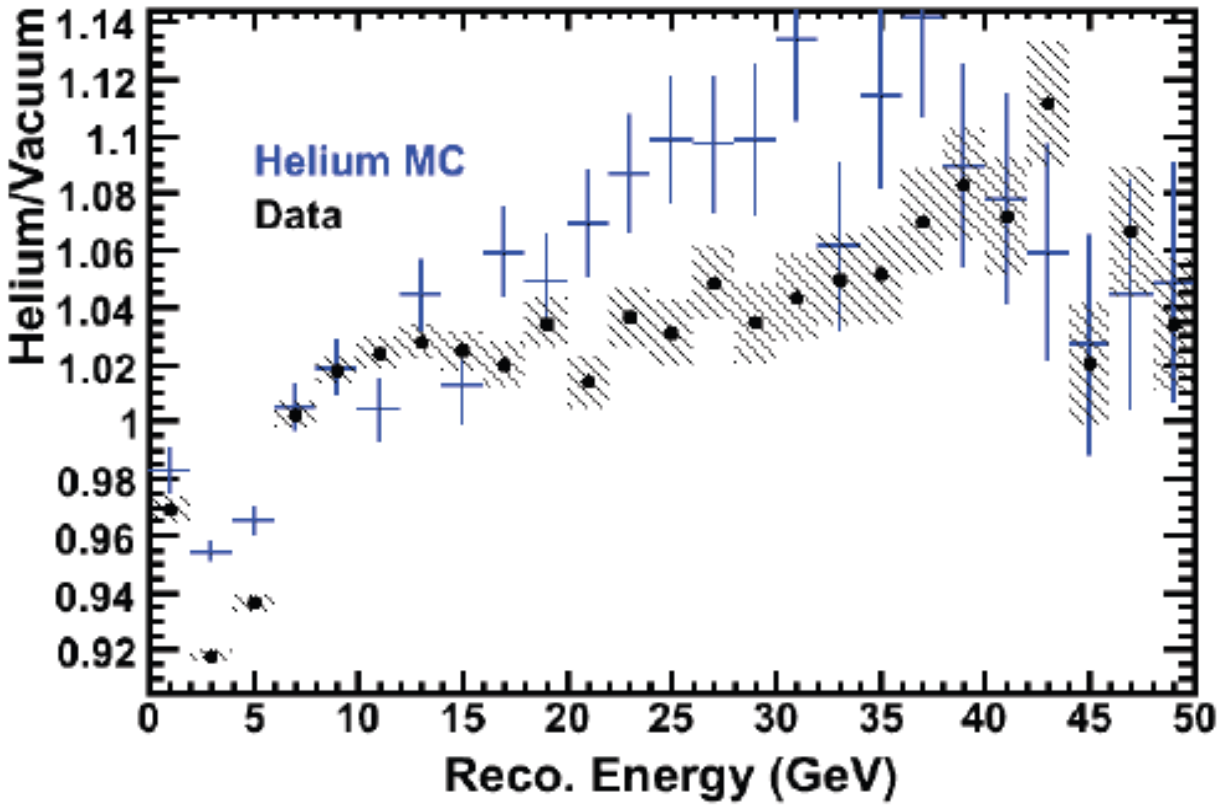
- **The decay pipe is the single most expensive element in the beamline. An evacuated DUSEL decay pipe would increase costs considerably.**
- **To reduce costs, the design will be for a He filled decay pipe at $\sim$ 1 atm.**
- **He in the decay pipe acts as an absorber - esp for lower energy hadrons, in addition you can get extra HE ν from proton beam remnant interactions with He.**

We need to assess the impact of He in the DUSEL decay pipe

MINOS lessons: He in Decay pipe

Alex Himmel

NuMI/MINOS ran Jan 25, 2005- August 2007 with an evacuated decay pipe (0.4 Torr). In September 2007, filled with He at 682.6 Torr (0.9atm).

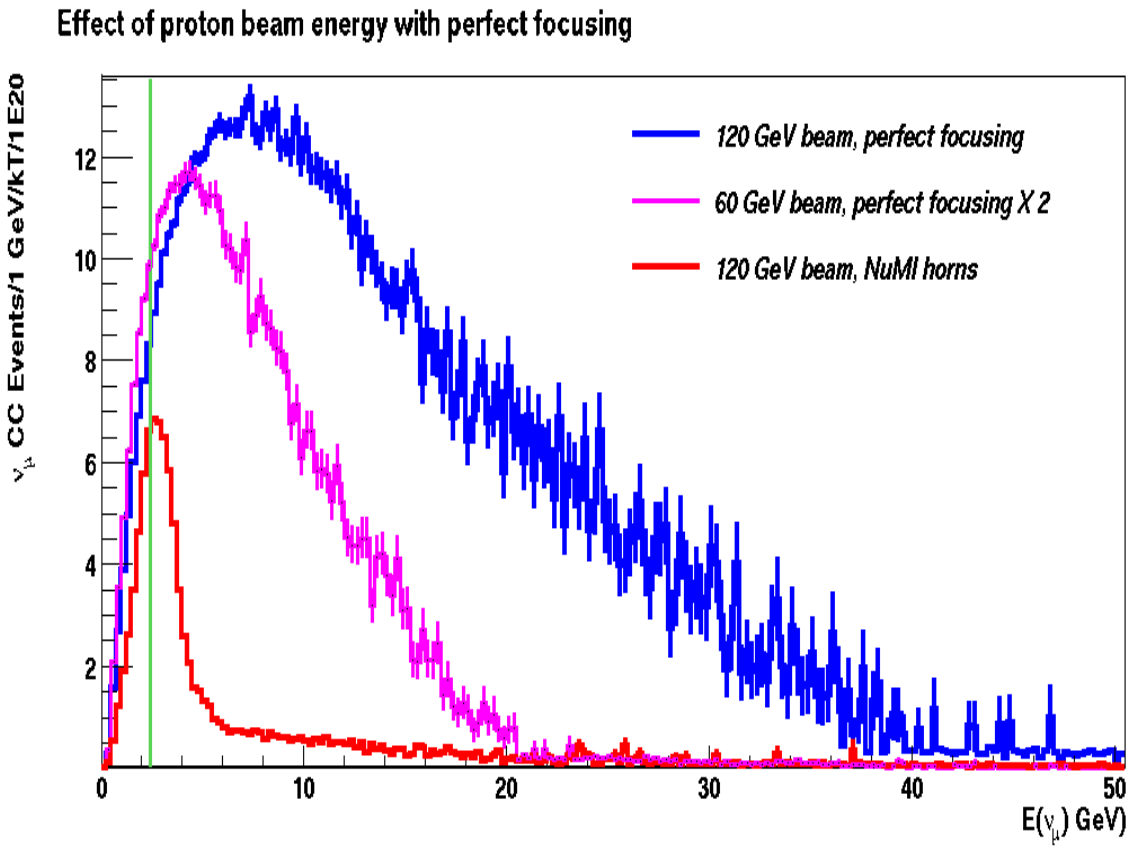


MINOS data: 2-3% increase in HE tails with He

DUSEL: This effect is dependant on decay pipe geometry

Impact of primary proton energy on HE tails

Study HE tails due to primary proton beam power using "PERFECT" focusing (no horns, set all hadron $p_T = 0$).



Lowering the beam energy is very effective at reducing HE tails

Summary and Conclusions

Summary

HE tails contribute 50-60% of NC background for ν_e appearance

HE tail ($>$ 5 GeV) adjustments to Fluka05 MC

Adjustment	Effect	Comment
MINOS beam fit (Data)	$\sim$ +20%	10% more flux at $<$ 5 GeV
He in beampipe (Data)	+3%	different beampipe geometry
1.5 m graphite plug (MC)	-38%	LE unchanged
0.5° off-axis (MC)	-38%	Less coverage at 1st maxima
p-beam 120 $\rightarrow$ 60 GeV	$-46\%^{**}$	At the same power!

** Estimated using AGS focusing not NuMI

With 120 GeV protons, plug is the best option for lowering HE tails

Whats next?

- **Waiting for results of MINOS efforts to model He in decay pipe using Fluka08 to finish He study.**
- **Continue study tunability of plugs - should we have a plug moves along the beam axis? Early studies indicate this changes where the cuttoff in energy starts.**
- **Move horns even closer?**
- **Target material properties (Jim & Byron)**
- **After Byron and Jim agree on a beam pipe shape - put all effects in MC: MINOS ND data corrections, correct target material, He in beam pipe, best plug and/or off-axis angle, decay pipe optimized to reduce volume. RECALCULATE SENSITIVITIES.**
- **Suggestions, please?**