Numix Meeting

Magnetic Horn Current Density

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Introduction

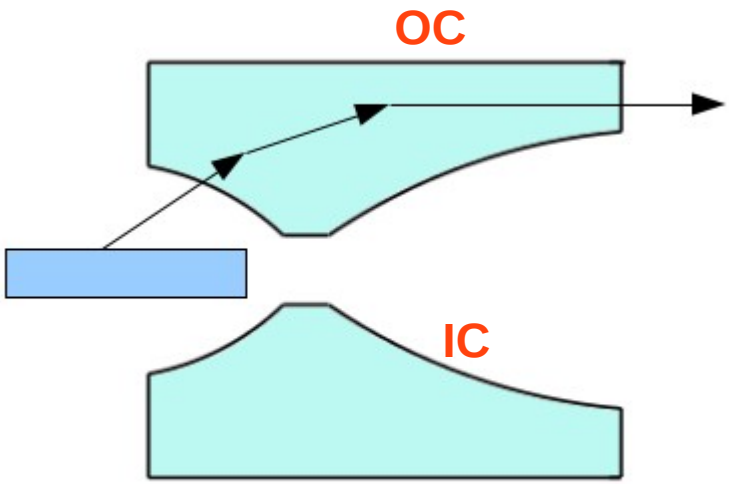
- In Minerva, the neutrino flux is crucial for cross section measurements.
- We are checking the magnetic model of the horn to check for any source of uncertainty.
- We will include them in the beam fit along with the low nu samples as has been previously shown (NUMIX Document 25).
- We started by checking the **horn current distribution** in the horn's inner conductor.

Motivation

- The distribution of the current in the horns' conducting metal affects the flux.
- The model used right now is not correct. It assumes infinite skin depth, which we know is not physically realistic.
- We would like to implement a more realistic model of the current distribution in g4numi, so it can be properly accounted for in the beam fit.

Horn Model in g4numi

- Two conductors (inner and outer), symmetric along the beam axis.
- Current *I* travels down the inner conductor (IC) and is returned via the outer conductor (OC), this provides a toroidal magnetic field.



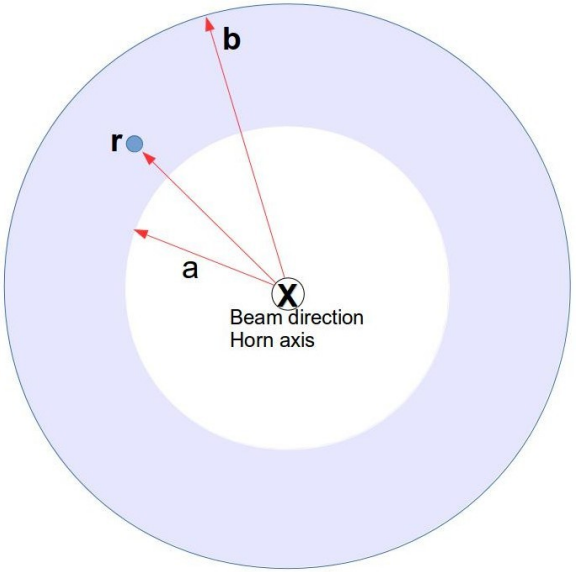
- **Inside horn** (Air): $B = \frac{\mu_0 I}{2\pi R} \propto \frac{1}{R}$ where $I = 182.1\ kA$ for le010z+/-185i

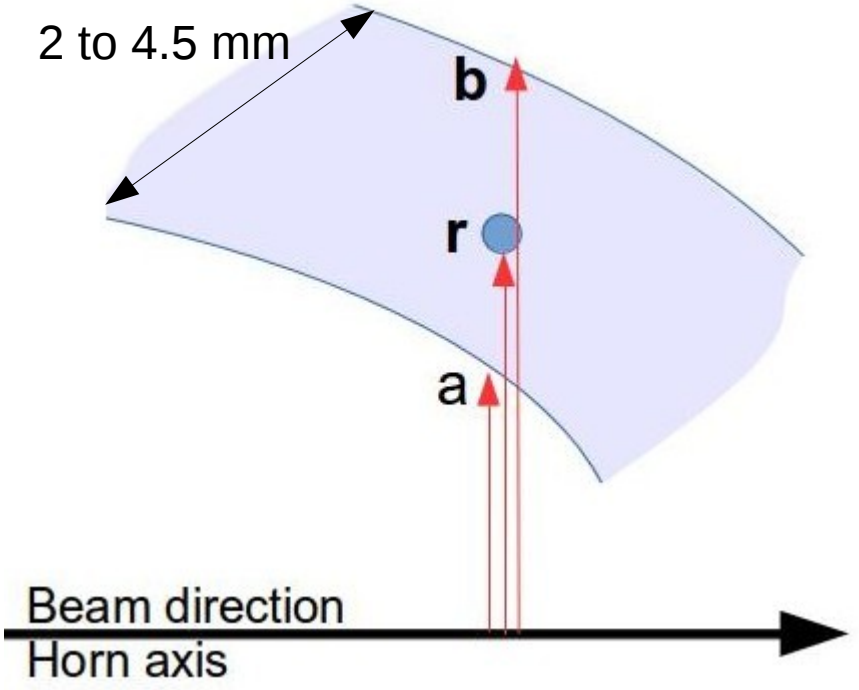
- **Inner Conductor (IC)** thickness (Al):
  - 4.5 mm: neck .
  - 2 mm elsewhere .
- **Outer Conductor (OC)** thickness (Al):
  - 2.54 cm .

We currently assume that the horn current uniformly distributed in the conductors, i.e. infinite skin depth.

Inner Conductor

- Considering just the IC of the magnetic horns:





- In the ideal magnetic horn all current would flow on its outer surface of the conductor (R=a).
- For a real conductor, we have to consider the skin depth (δ).
- There is a radial symmetry in the transversal section.

Analytical Solution

- The particles that spend more time passing through IC are affected by the current model (mainly **underfocused pions** in the falling edge of the neutrino peak. See plots to come).

Models:

- In g4numi, we assume a uniformly distributed horn current (δ->∞).
- The classic example is to use exponential decay, but this is just for a semi-infinite plane. Not useful here.....
- **More realistic:** Use the analytical solution for a transversal section:
  - Bessel and Neumann functions with complex arguments and boundary conditions.

$$J_z(r) = C_1\, j_0(\tau r) + C_2\, n_0(\tau r) \qquad \tau = \sqrt{i}\,\frac{\sqrt{(2)}}{\delta}$$

  - We will take Neumann (decrease with the radius).

Skin Depth

- Conductivity of Aluminum at 20 ^{0}C : $\sigma^{-1} = 28.2\, n\Omega\, m$
- Permeability of Aluminum at 20 ^{0}C : $\mu = 1.2569701 \times 10^{-6}\, H/m$
- Intensity pulse is approximately half sine wave.
- Frequency: $\omega = \frac{\pi}{T} = \frac{\pi}{2.3\, ms}$

$$\delta = \sqrt{\frac{2}{\sigma \mu \omega}} = 5.73\, mm$$

Skin Depth Uncertainty

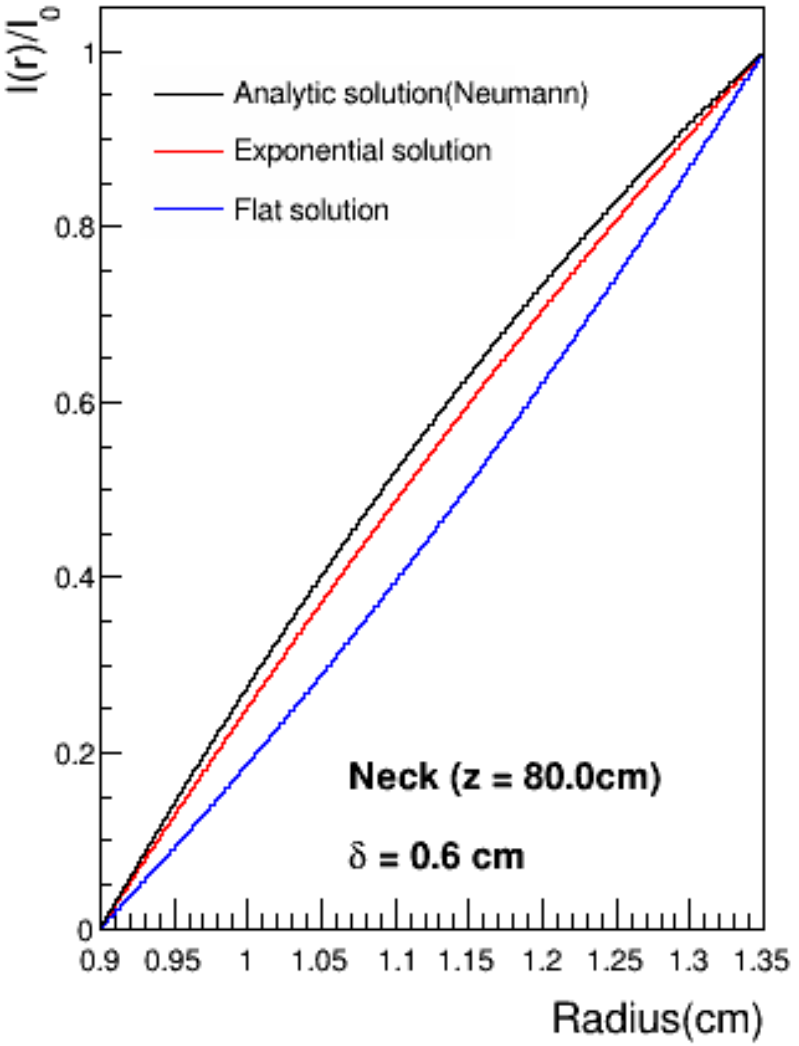
However:

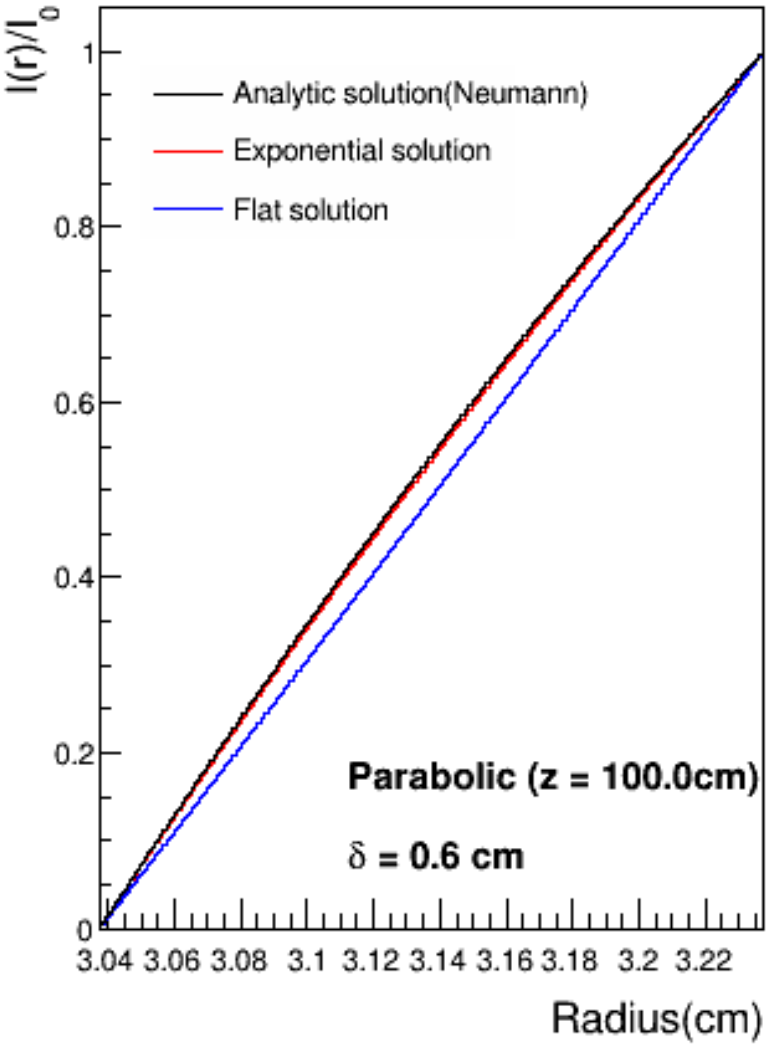
- Conductivity: the temperature gradient changes the conductivity (Zhijing Tang, “About the current distribution in Numi Horn”. 2006). Maximum change: 4%. (**check**) .
- Temperature at Neck1 : 22.8 ^{0}C (NuMI Technical Design Handbook). For Neck2: <7.1 ^{0}C .

This could be a potential uncertainty of the skin depth value.

Fractional Current

- Linear solution corresponds to infinite skin depth.
- For lower values of the radius, the linear, exponential and analytical solutions differs.





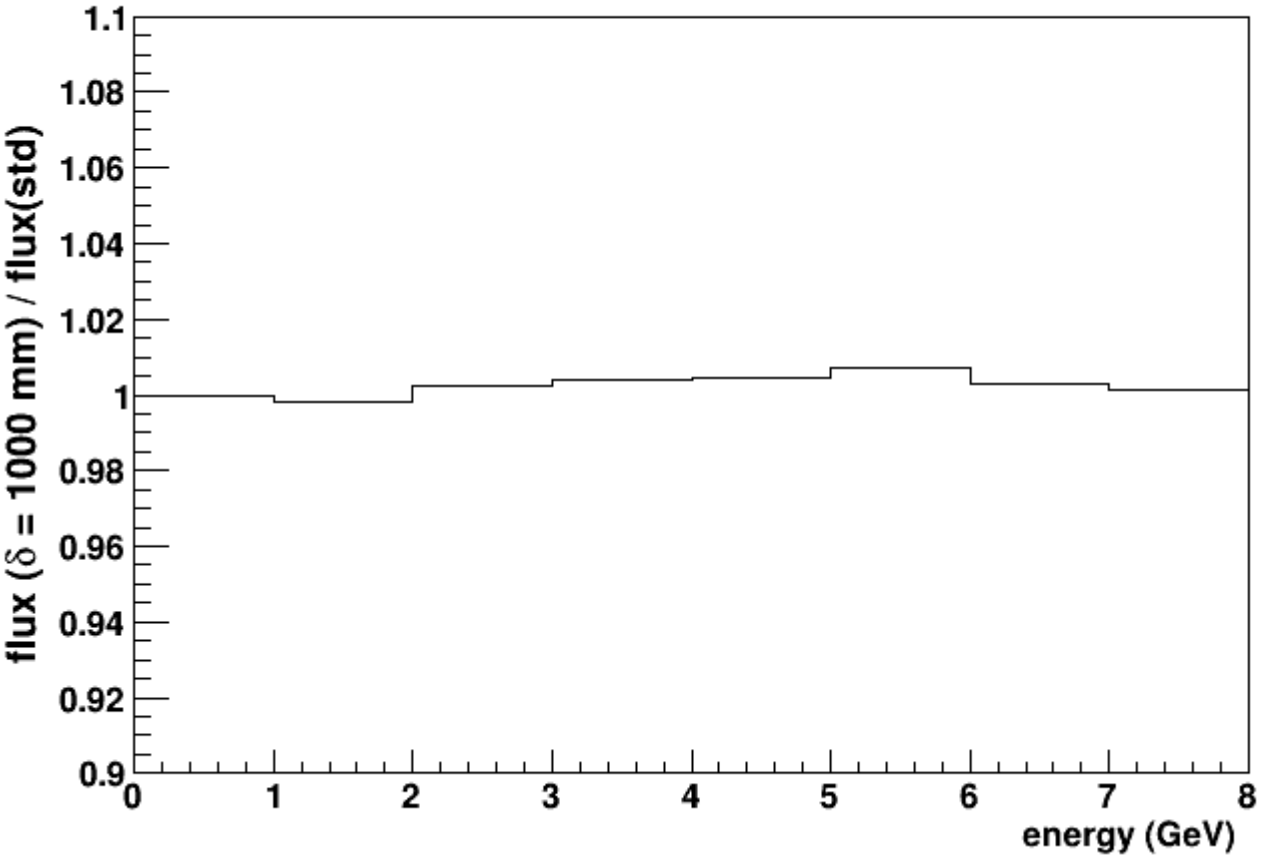
Implementation in g4numi

- To test the effect on the flux, We created a library with the necessary formulas for g4numi (NumiKelvinFunctions), based on ROOT's implementation of these same functions.
- We Modified NumiMagneticFieldIC to include the Neumann solution for $I(r)/I(b)$.
- We include two new messengers (in the numix Minerva branch):
  - /NuMI/det/UseHCD true .
  - /NuMI/det/SkinDepth XX mm .

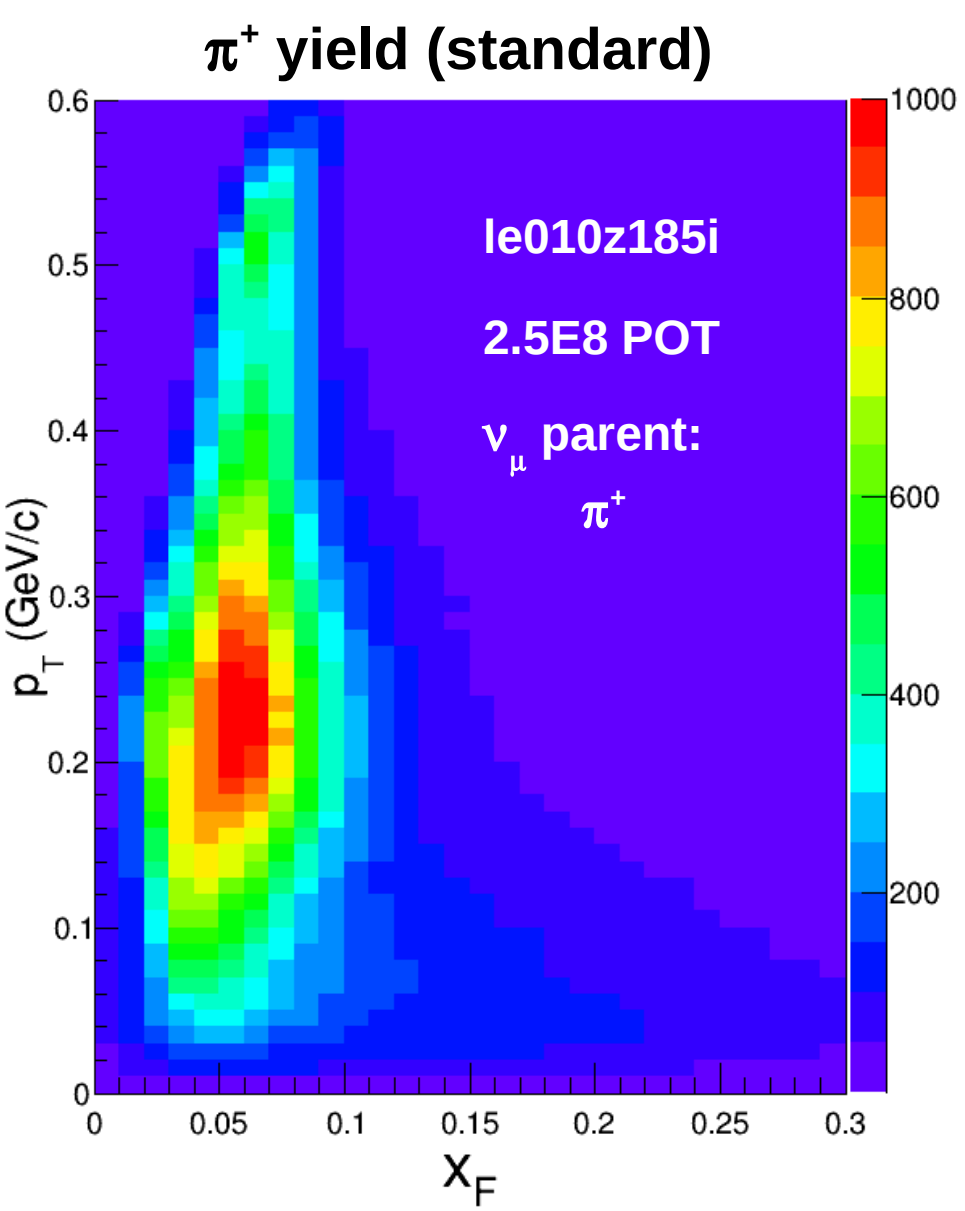
Cross check

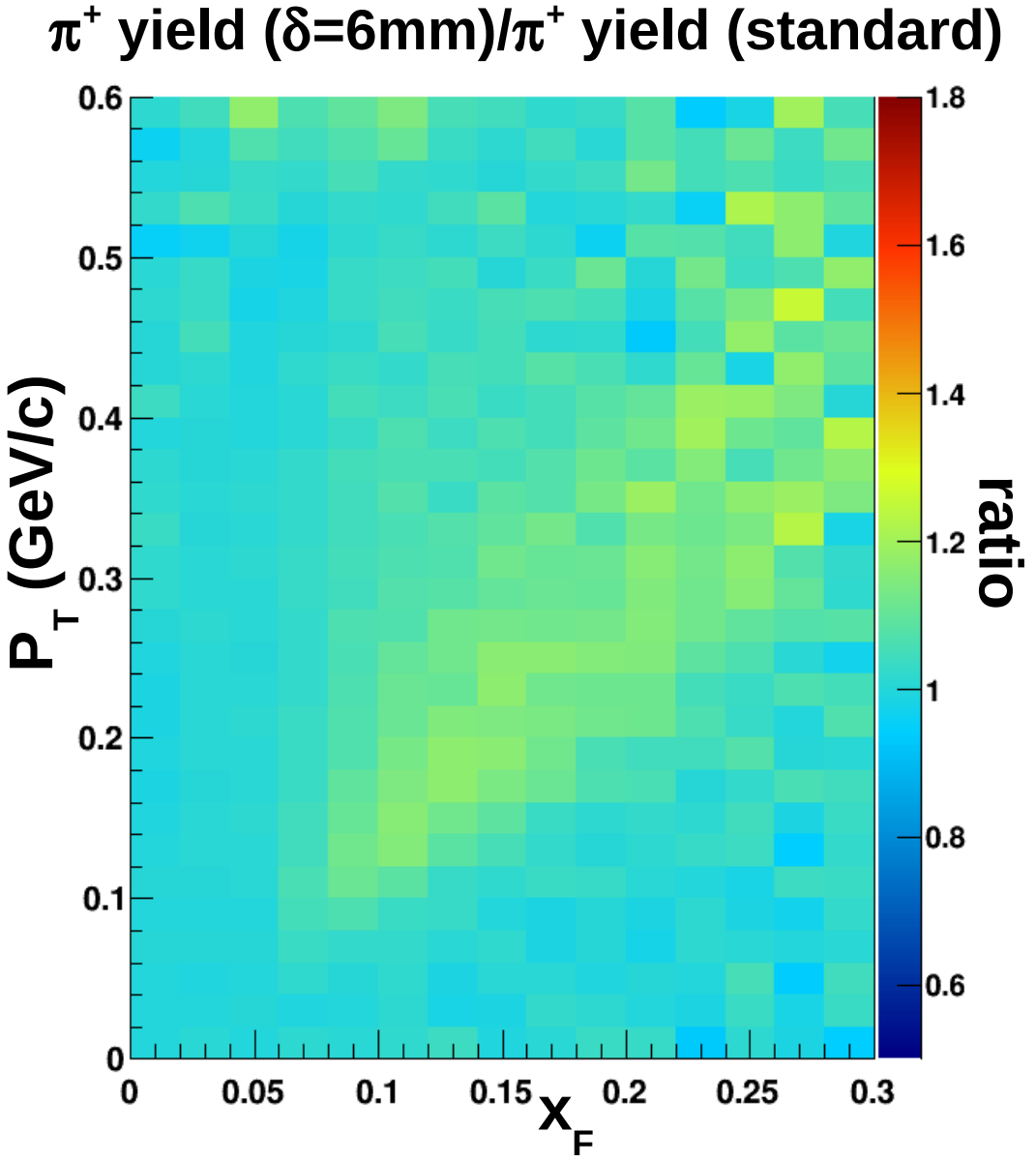
- I checked many output values of my Kelvin function code against the standard tables and they agreed.

- Also, I ran my code using the current “wrong” skin depth value (δ = 1000 mm) and compared with the standard flux (calculated with infinite skin depth) and they agree.



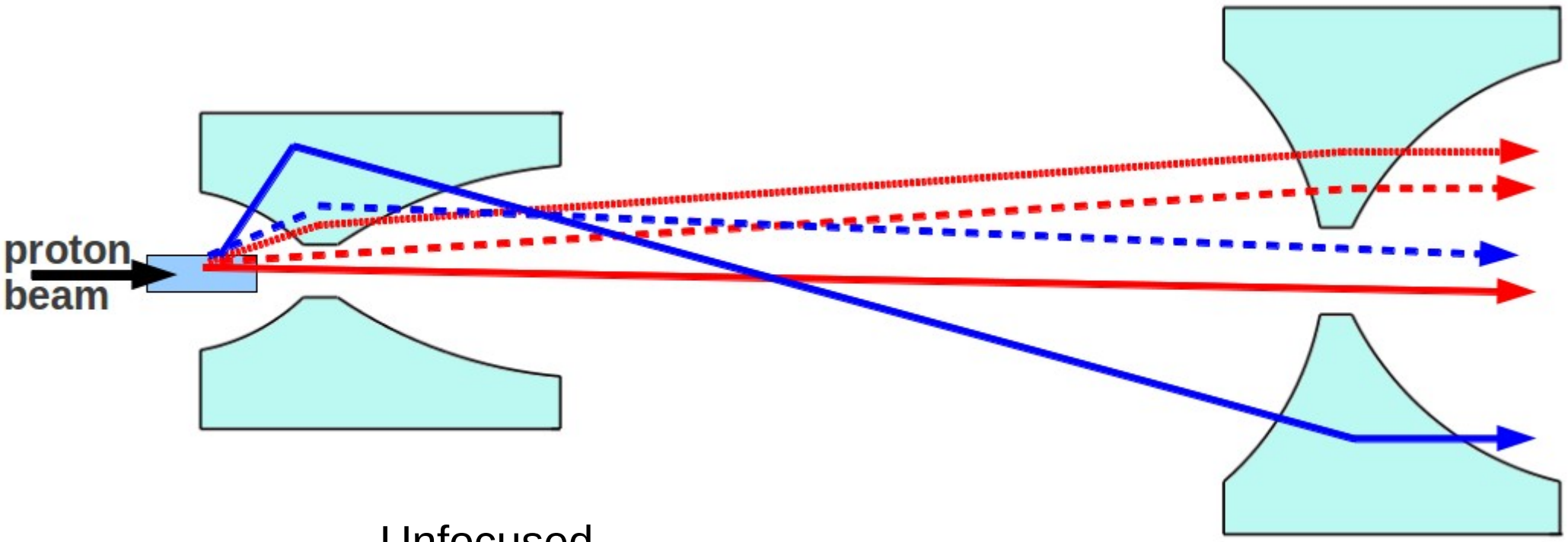
Pion plus muon neutrino parent





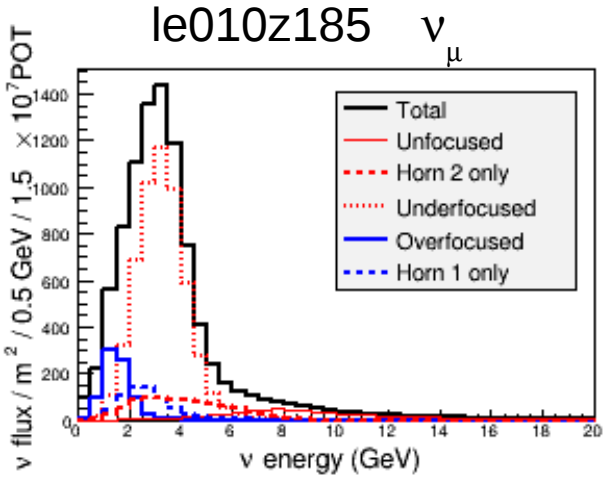
- Part of the focusing is affected

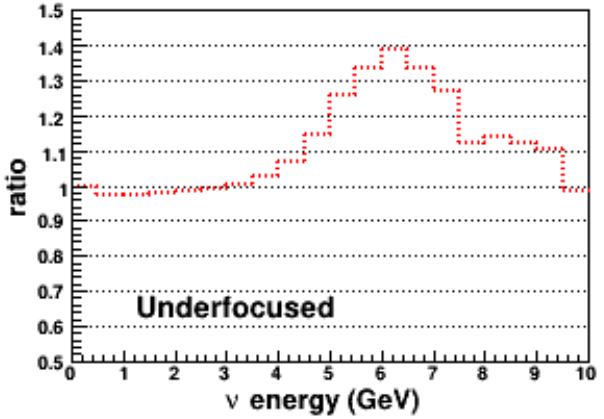
Looking into the Focusing components

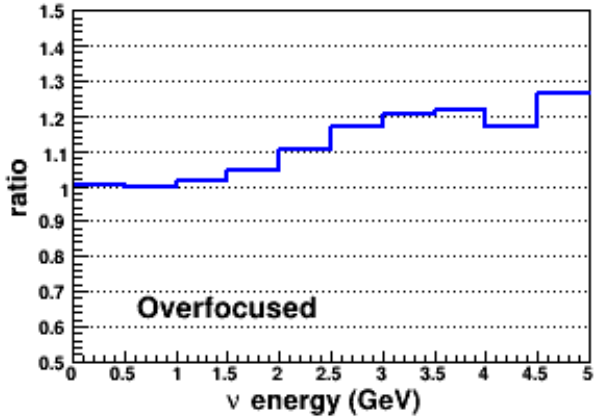


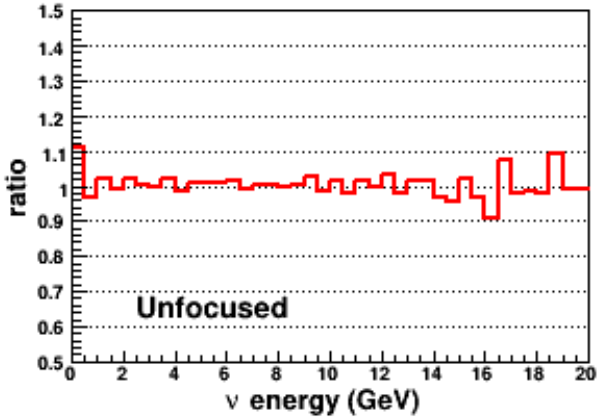
Unfocused
Horn 2 only
Underfocused
Overfocused
Horn 1 only

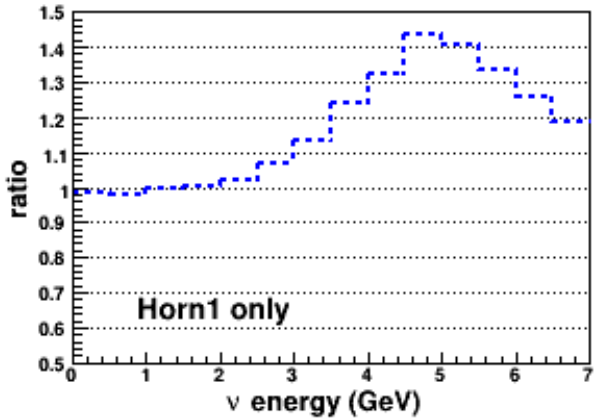
Breakdown by Focusing Component (δ=6mm)/(standard)

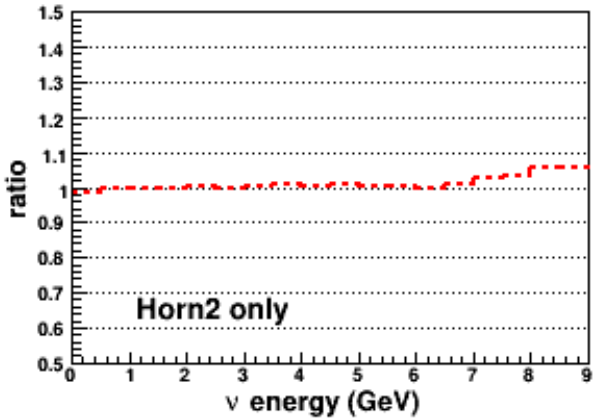




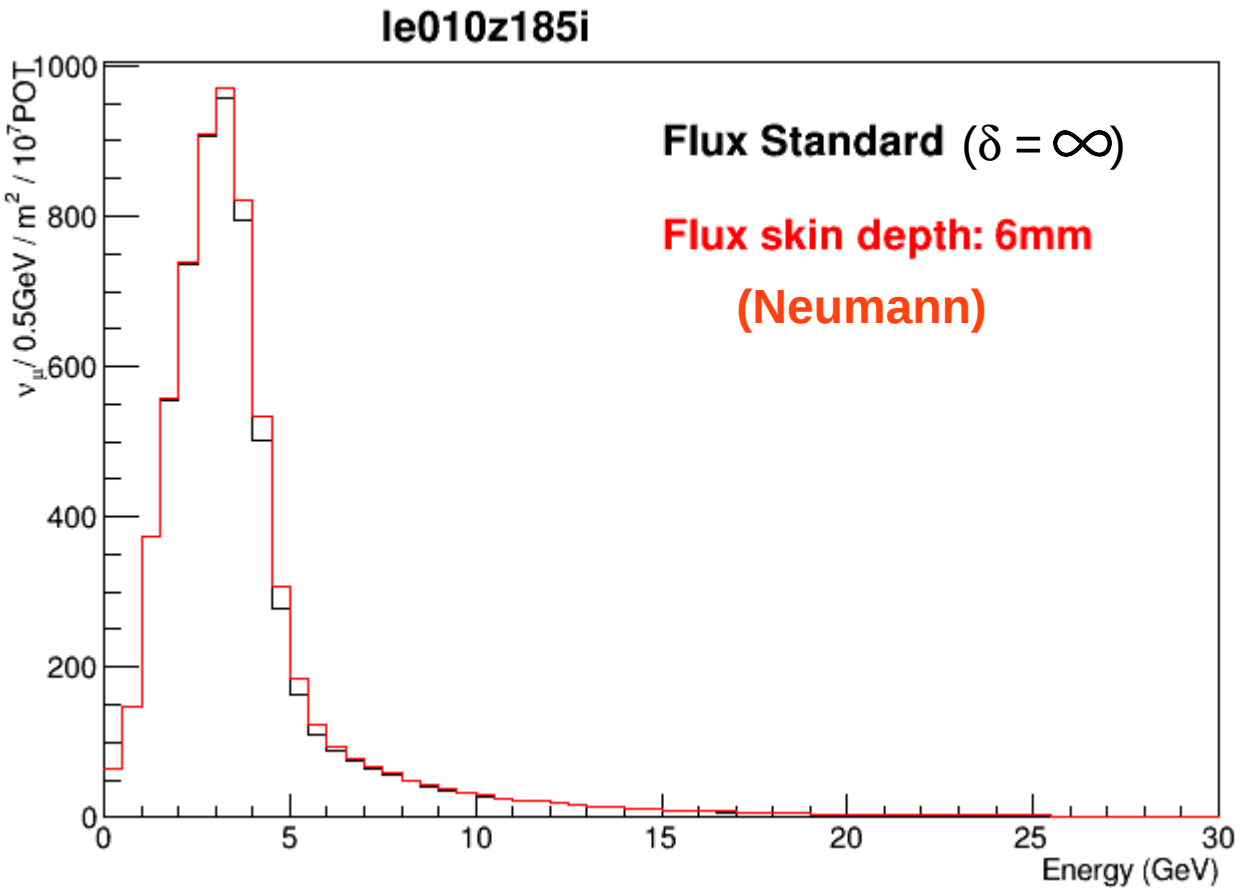






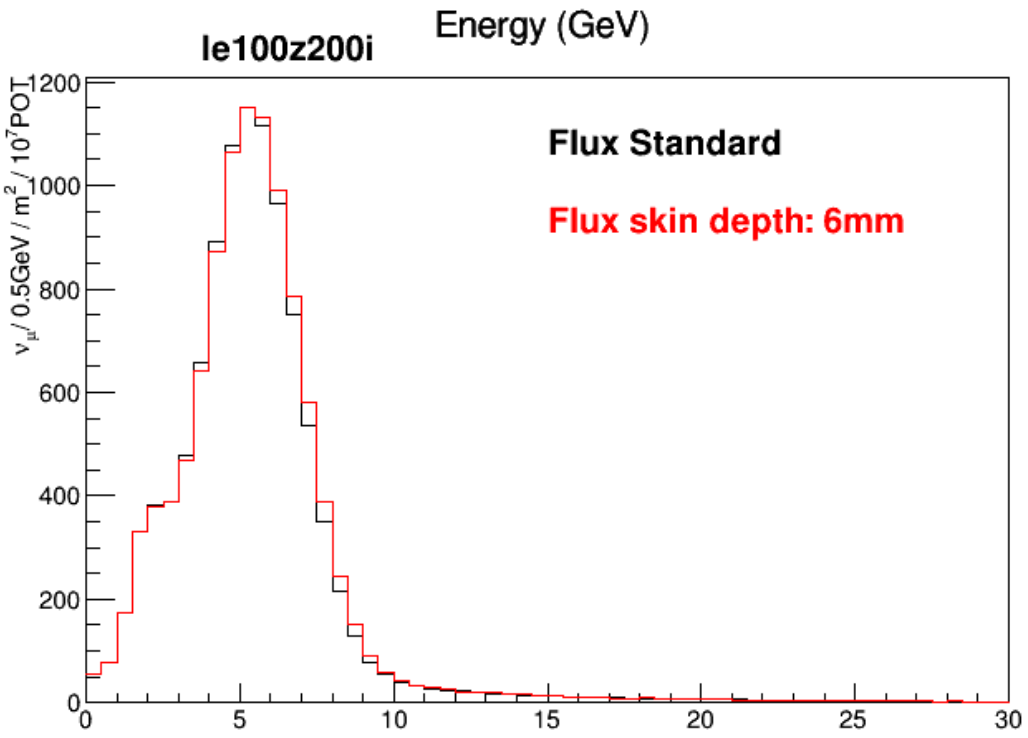


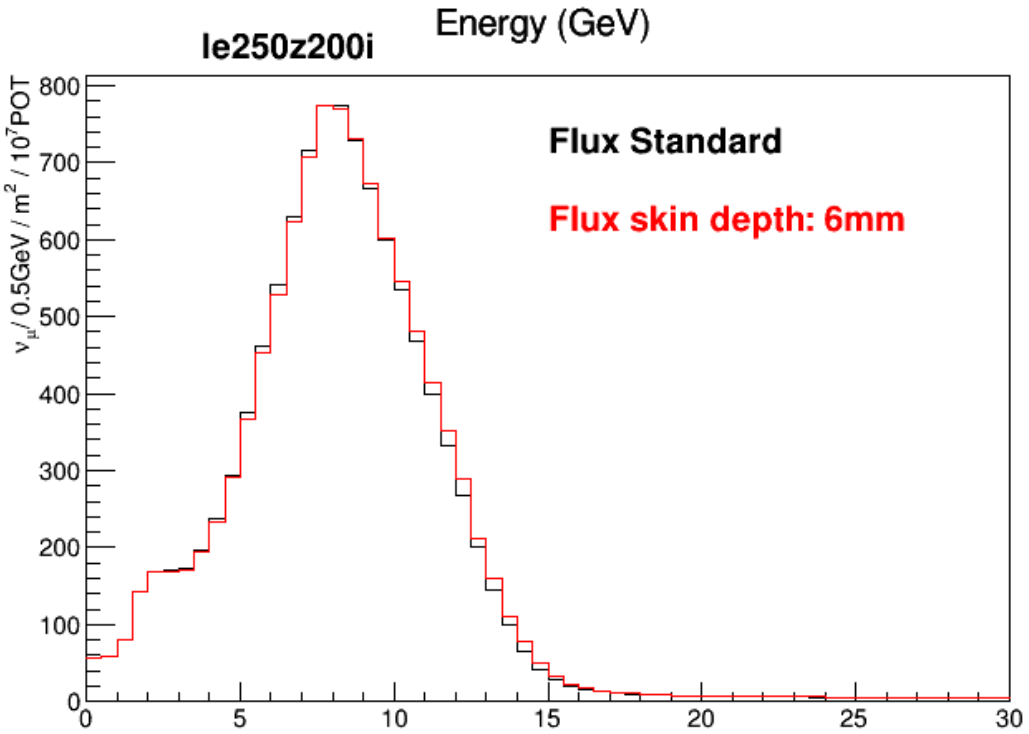
LE010z185i Flux



- The standard flux has infinite skin depth.
- Basically, the falling edge of the peak is affected in the Low Energy Configuration.

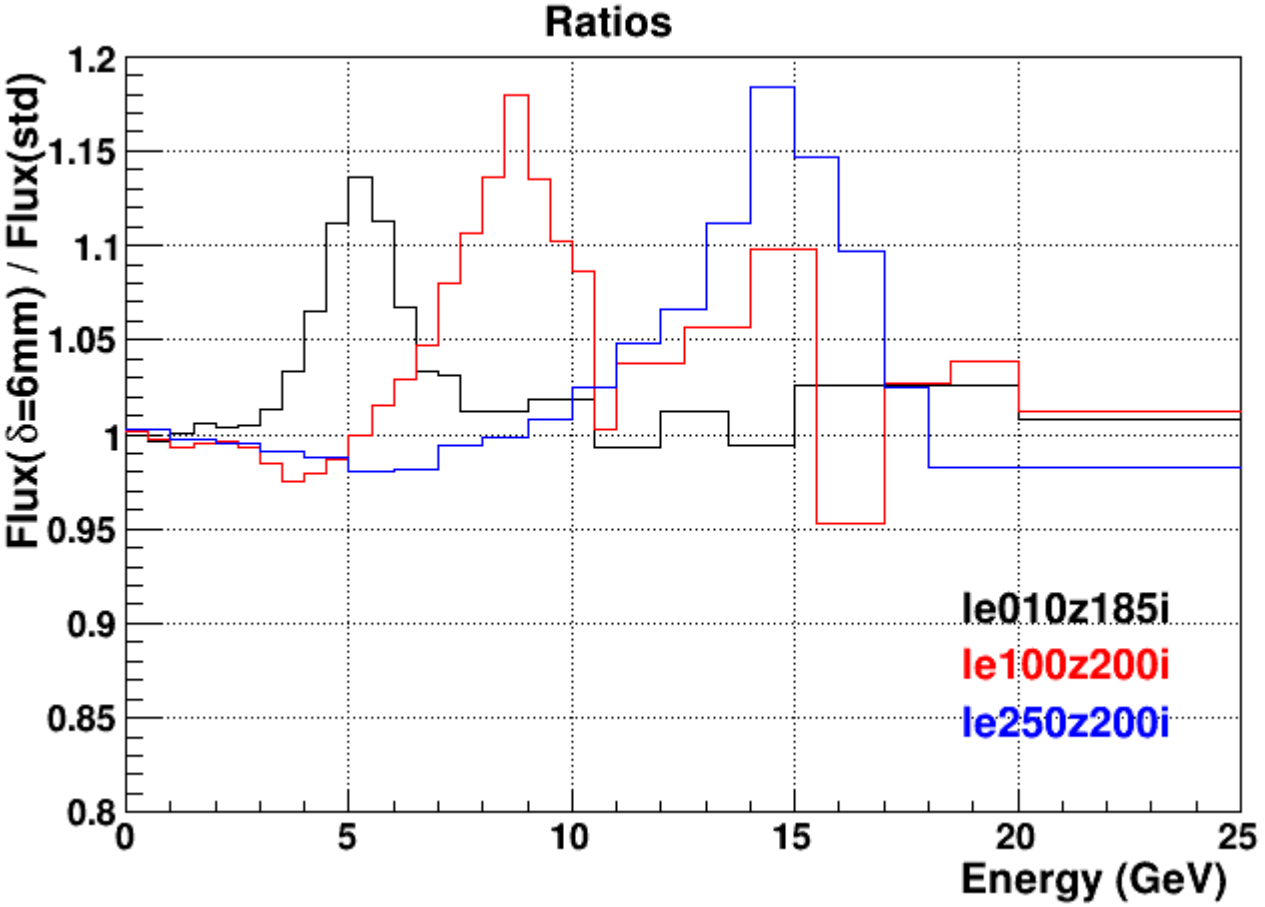
LE100z200i and LE250z200i





- For the medium and high energy the effects is also around the peak.

LE010z185i Ratio



Conclusion

- The Flux is vital for Minerva analysis.
- Even small mis-modeling of the magnetic horns can give us discrepancies between our data and our Monte Carlo.
- If we implement the correct analytical solution for the horn current distribution, the only parameter with an uncertainty should be the skin depth.
- We have implemented an analytical solution with the skin depth as the only parameter.

Upcoming Steps

- Include systematics uncertainties from the horn current magnitude (currently being worked on by Bruce Howard) and distribution, particularly getting a realistic uncertainty on the skin depth.
- Study the effect of the residual magnetic field in the neck.
- Look for any deviation of the 1/r distribution of the Magnetic Field inside of the horn.

backup

Current density