ν_τ appearance optimization

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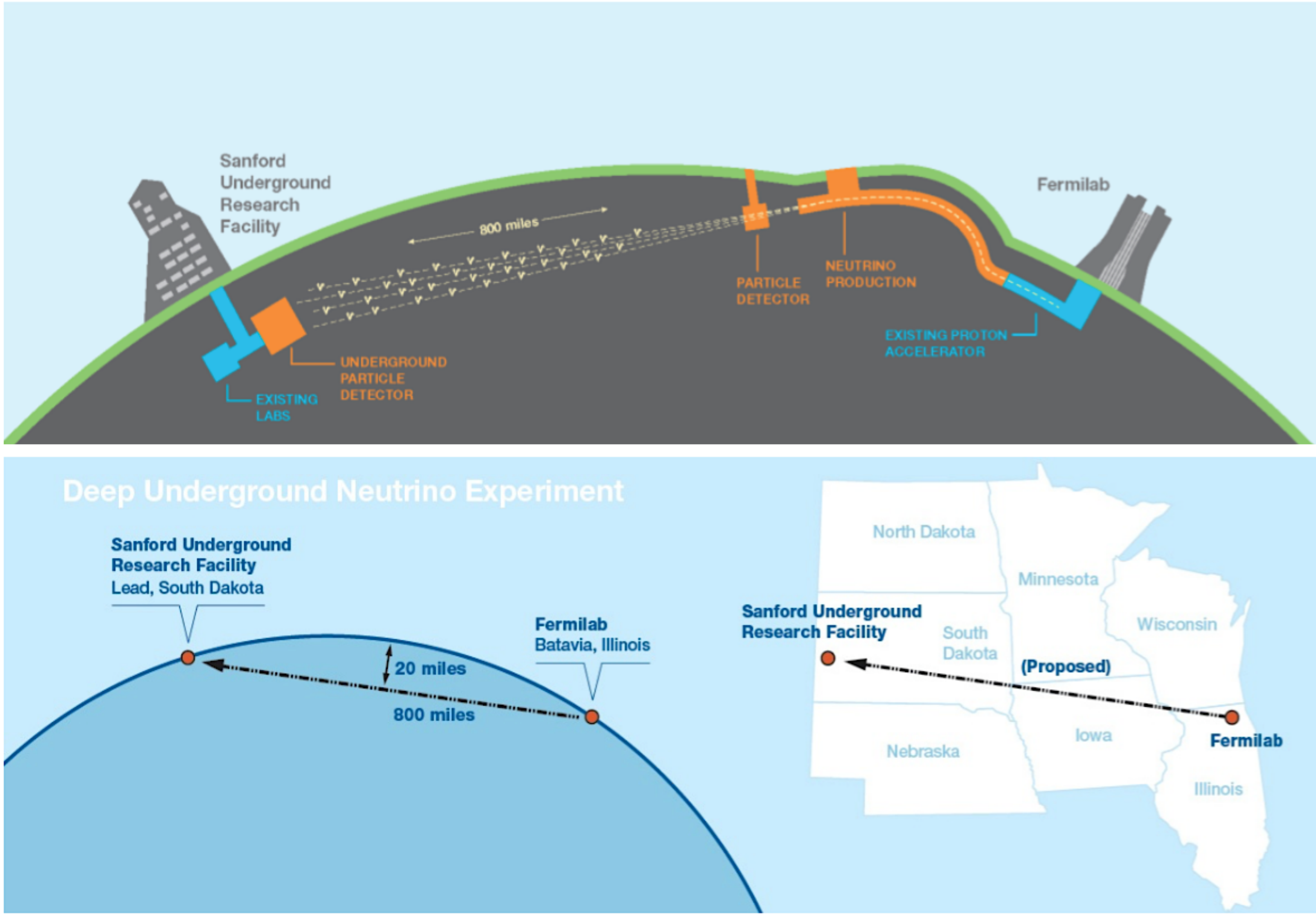
Final presentation

23 September 2016

Outline

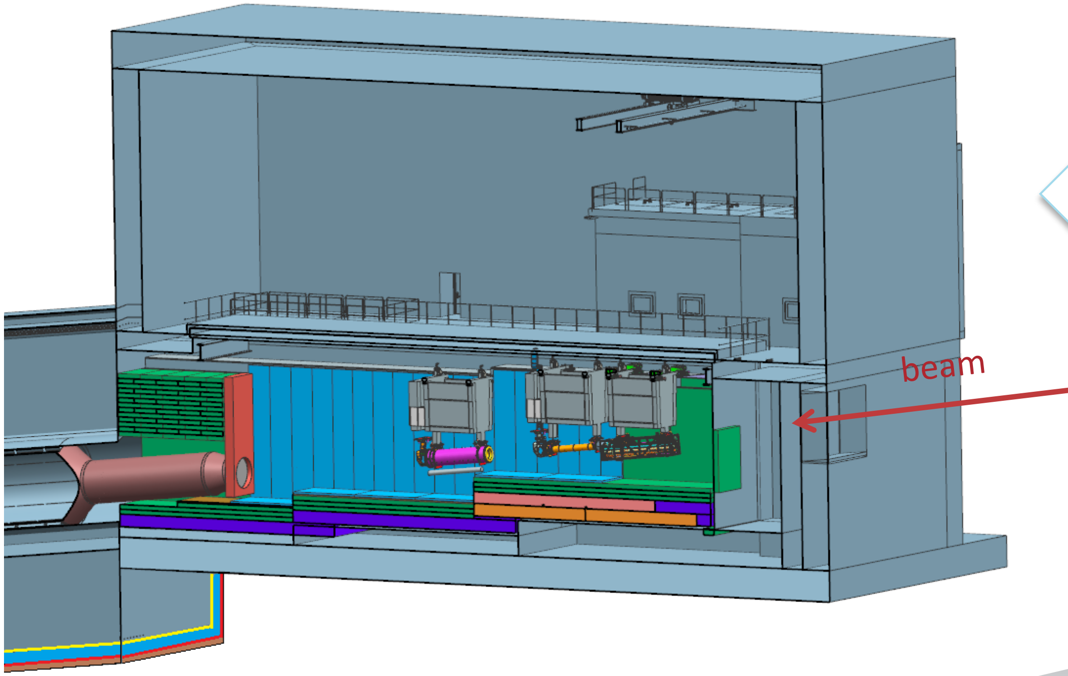
- DUNE experiment design
  - Target hall
  - Magnetic horns
  - Different targets
- ν_τ physics
- ν_τ appearance optimization
  - Target and the second horn placement
    - ν_μ fluxes
  - Second horn rescale
  - Target optimization
- Work left to do toward optimization
- Conclusions

DUNE experiment



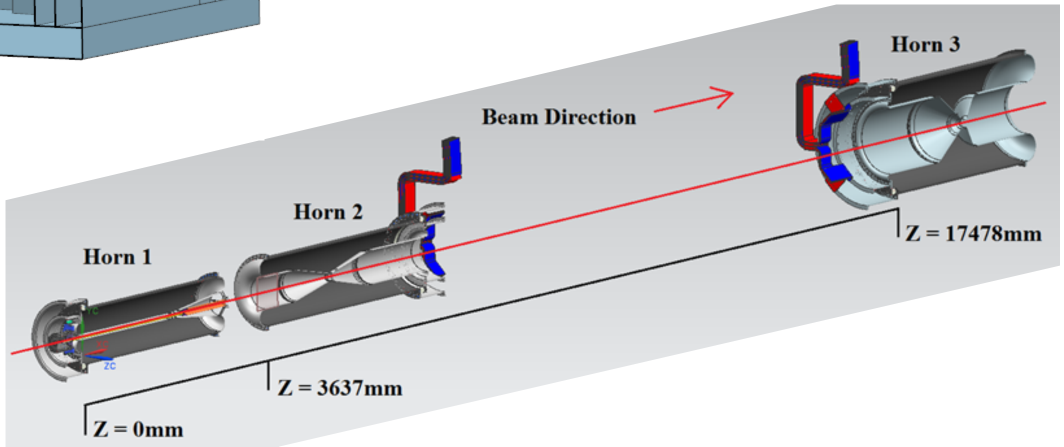
DUNE experiment design

Target hall



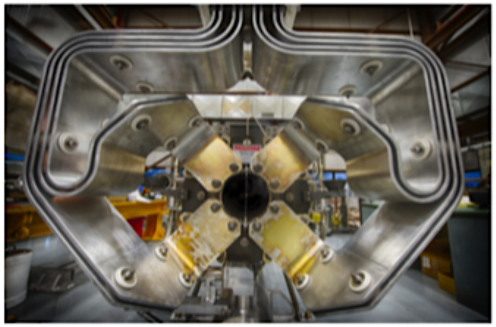
Target hall
in reference design
with two NuMI horns

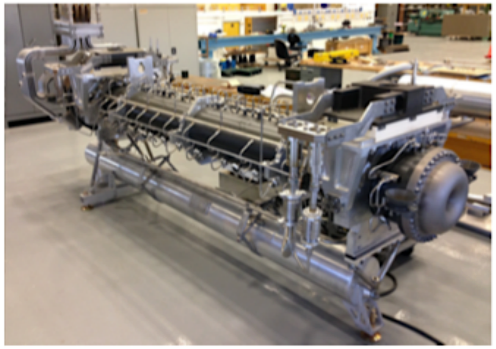
Three horns for the optimized design (better for low energy experiments)

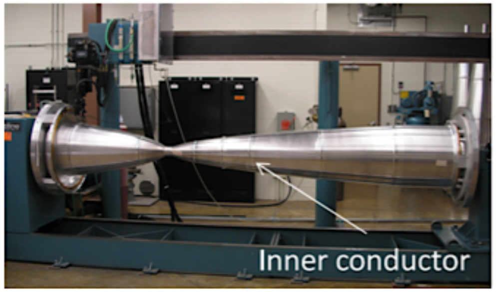


DUNE experiment design

Magnetic horns

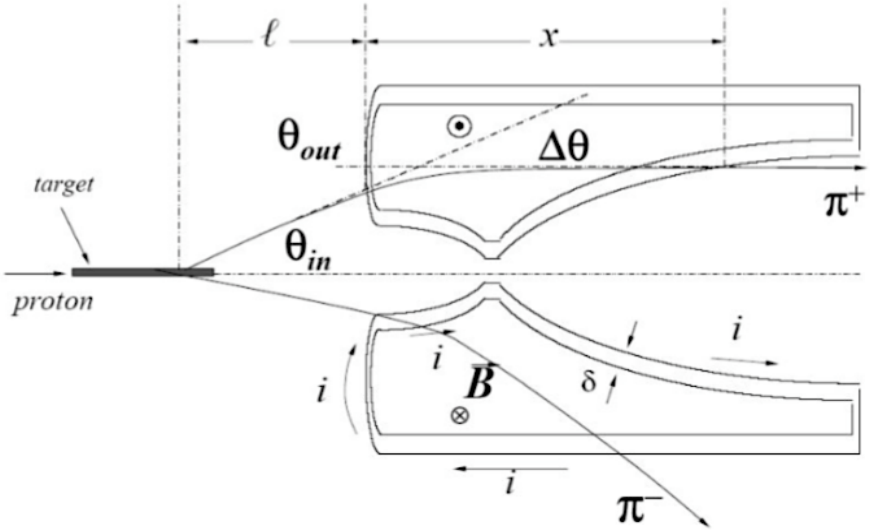






PARABOLIC HORN

- Focuses a given momentum for all possible angles of entry into the horn.
- For a given shape and current the focal length of the horn is proportional to the particle momentum.
- High energy particles could be under focused (not fully strengthen) while low energy particles could be over focused.

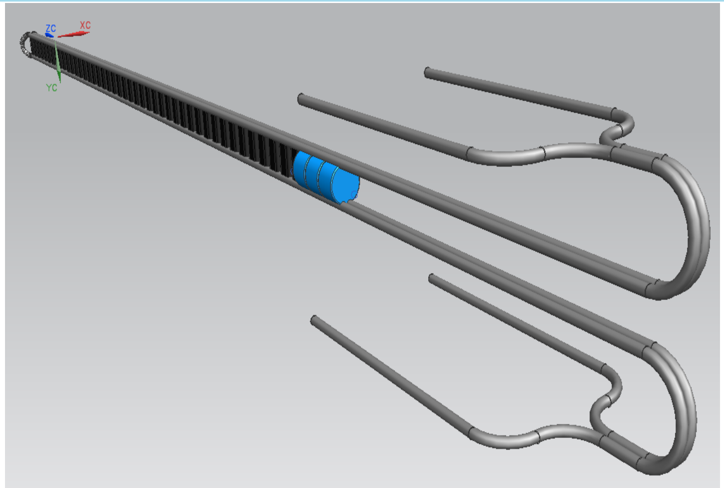


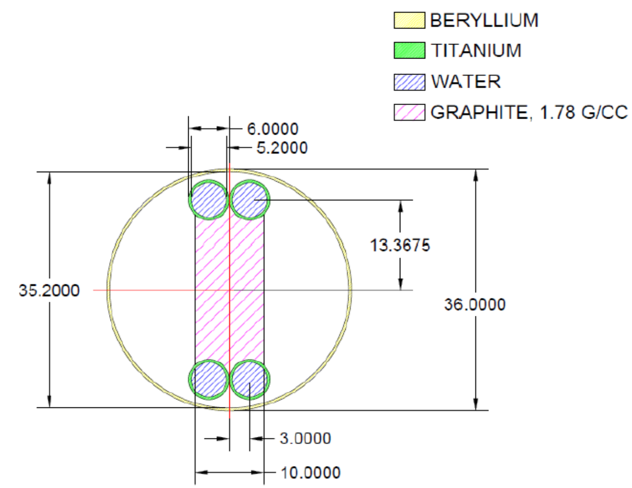
DUNE experiment design

Different targets

NuMI target

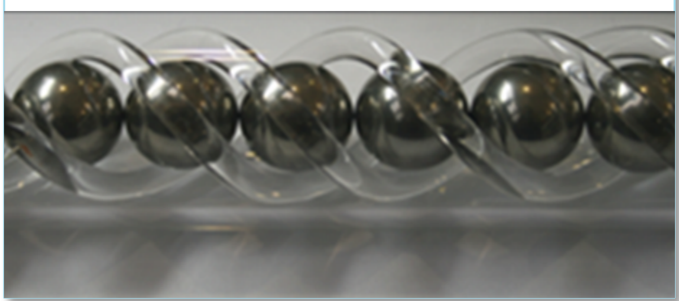
47 graphite target segments, each 2 cm long and spaced 0.2 mm apart, 10 mm in width





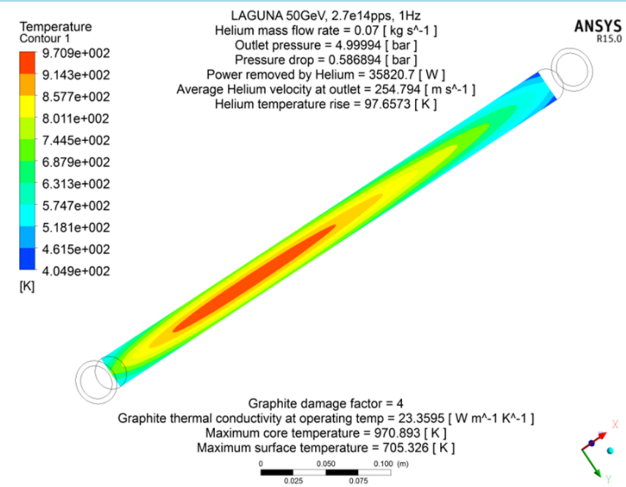
Multi spheres target

Helium cooled spherical array

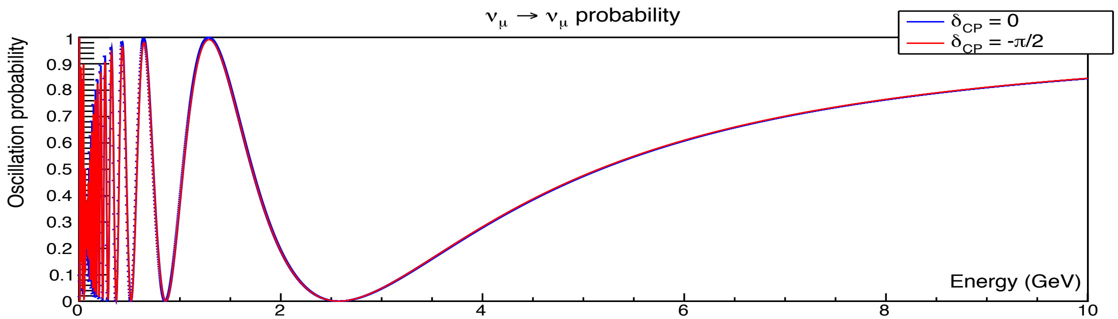


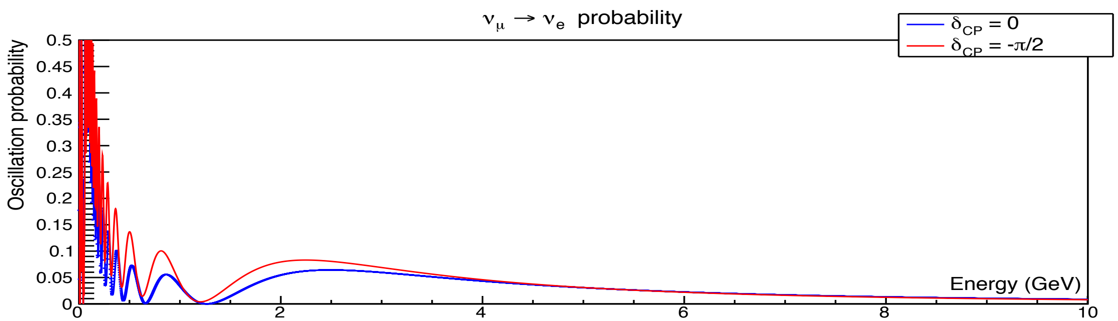
Cylindrical target

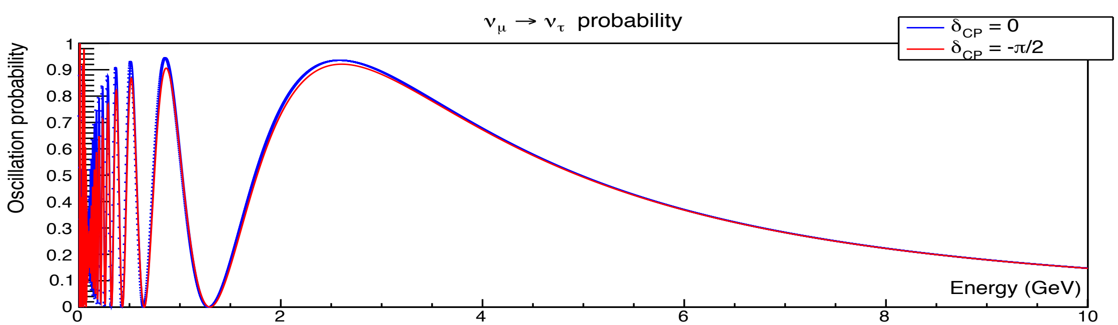
Helium cooled graphite rod



Neutrino oscillation probability







In the theory of oscillations flavour states are superpositions of mass eigenstates

$$|\nu_\alpha\rangle = \sum_i U_{\alpha i}|\nu_i\rangle$$

where $\alpha = e, \mu, \tau$.

Here the computation of the oscillation probability is made by OscProbability.C implemented in the LBNF code.

Parameters are updated to 2016 and the distance at which oscillations are observed is 1294 km (DUNE far detector).

ν_τ : why, how and what we already know

WHY

To test the unitariety of PNMS matrix.

HOW

- ν_τ are only distinguishable in CC interactions, when they produce a tau lepton. Since tau is heavy, neutrino should have a minimum energy of 3.5 GeV to interact with the detector.
- High energy pions are needed to produce high energy neutrinos.
- Is necessary to move the target far from horn 1 to cut low energy neutrinos out of the beam and to improve the focusing system.

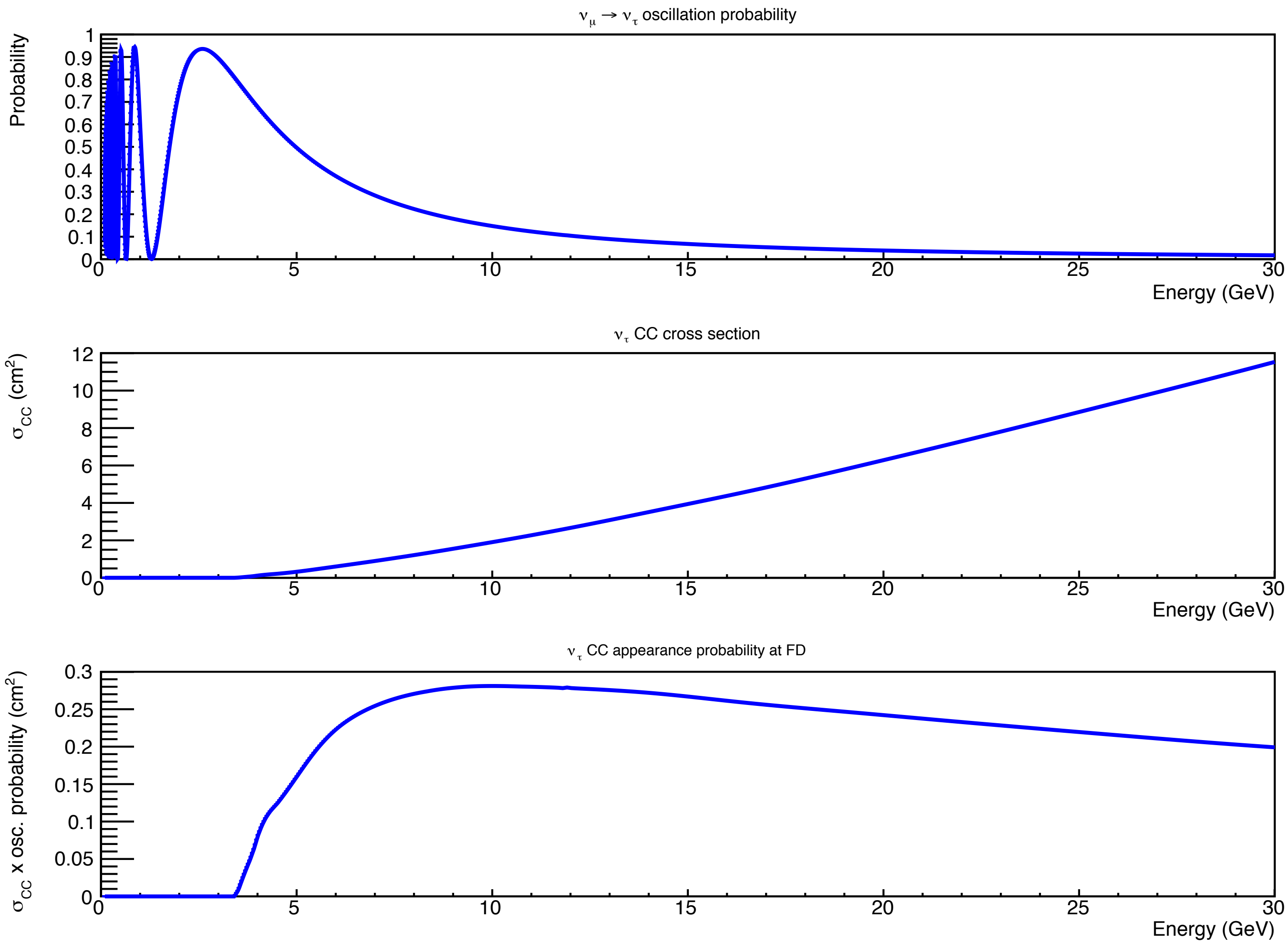
WHAT WE KNOW

Not too much…

5 events from Opera (from oscillations) and 12 from DONUT (from D_s decay)

ν_τ physics

ν_τ appearance probability at DUNE far detector



Cross section evaluated by GENIE included in the LBNF code

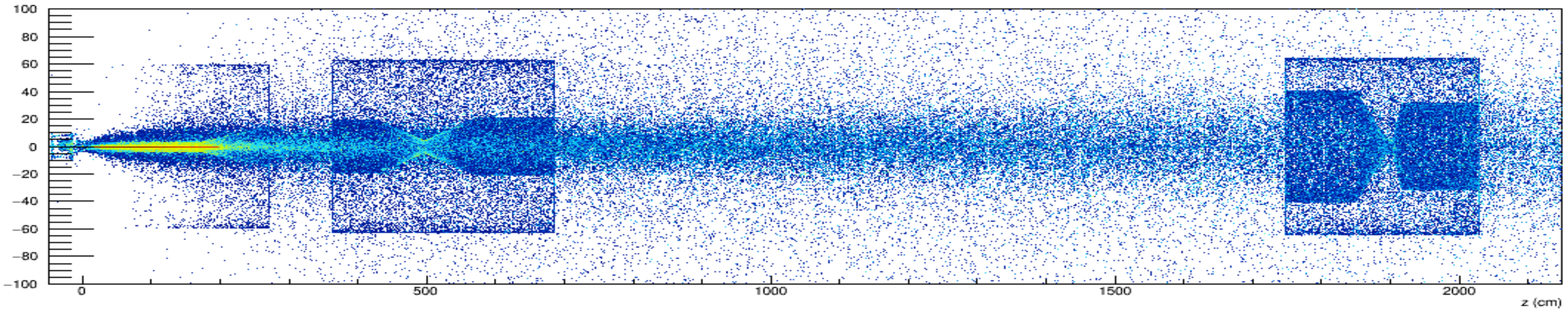
ν_τ appearance optimization

Reference vs. optimized design

Optimized design

128 ν_τ CC events at FD per 40kton per year

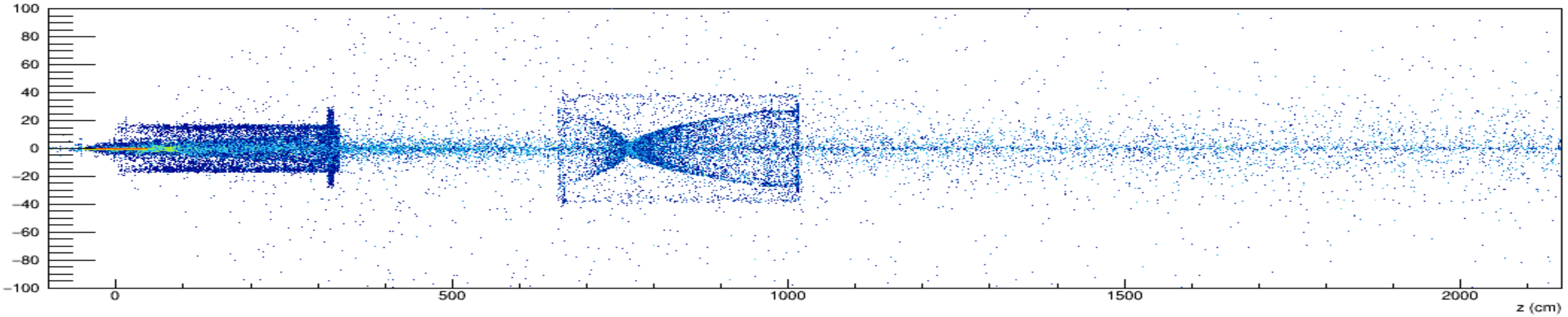
Standard deviation = 8   Mean error = 1



Reference design

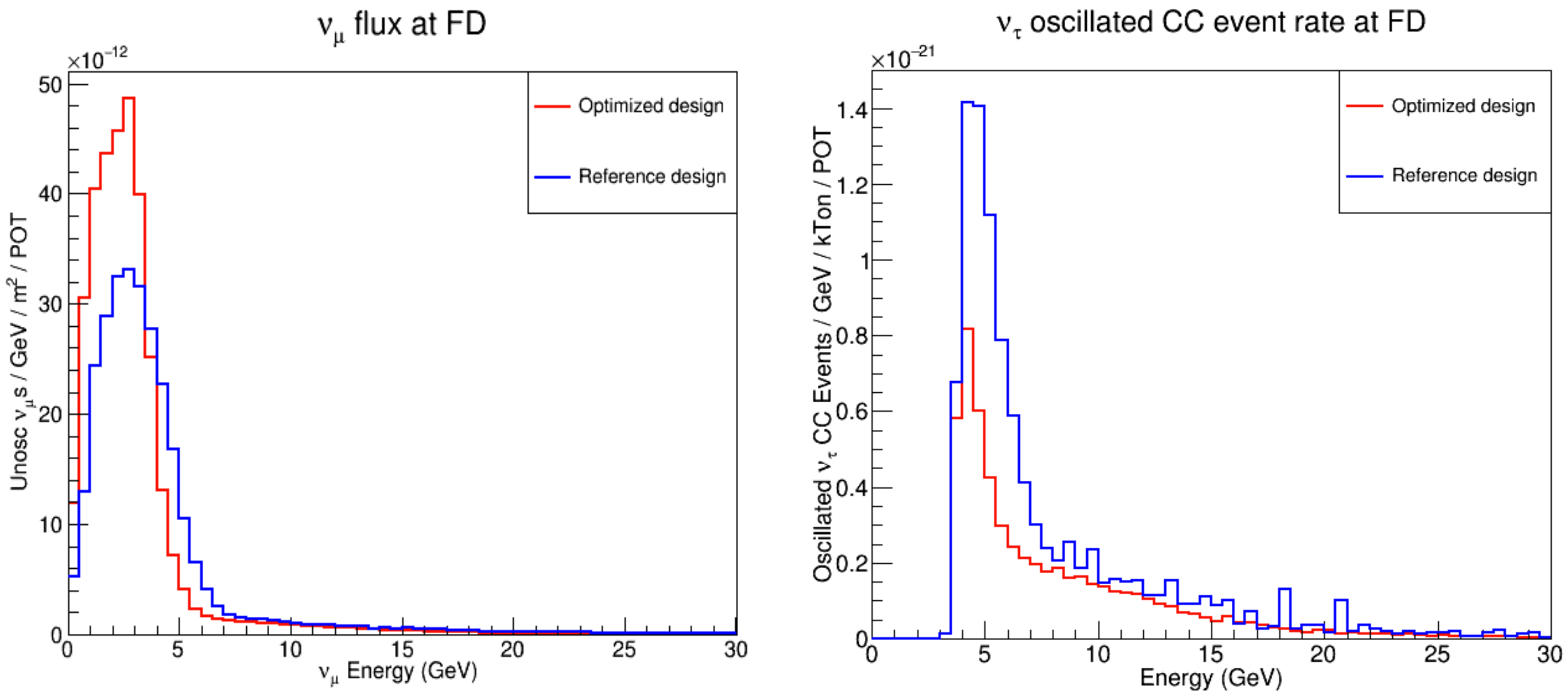
225 ν_τ CC events at FD per 40kton per year

Standard deviation = 55   Mean error = 3



ν_τ appearance optimization

Reference vs. optimized design



ν_τ appearance optimization

Target and second horn placement

Setups for the simulation

- Buffle not installed
- Shield not installed
- Decay pipe snout not installed
- Horns
  - 230 kA current
  - 1.2 MW
- Beam
  - 120 GeV proton momentum
  - Beam sigma X = 1.7 mm
  - Beam sigma Y = 1.7 mm

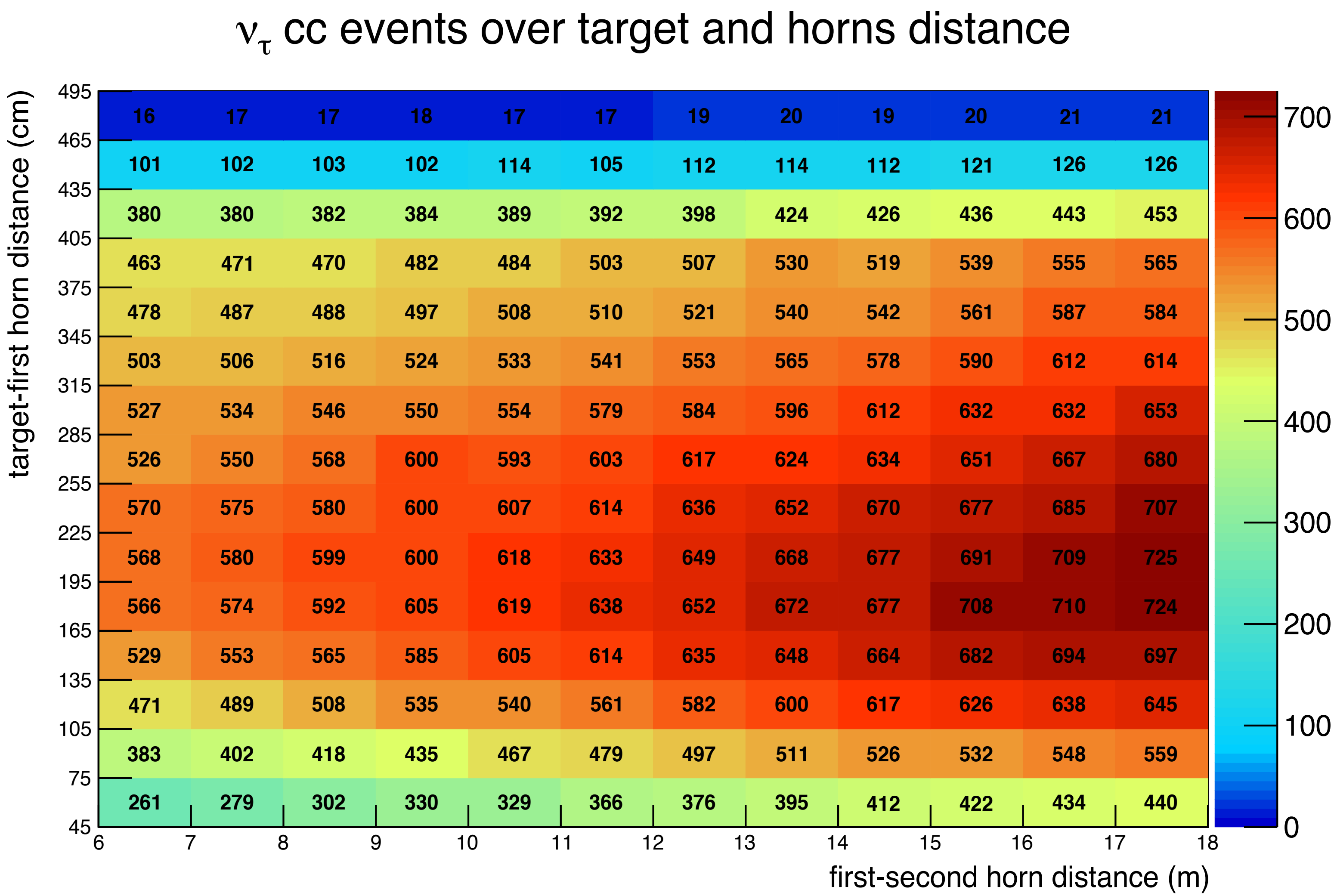
- NuMI target
  - Graphite
  - Fin width = 10.0 mm
  - Target length = 1 m

100 jobs with 100k POT each for different distances of the target and of horn 2 from the zero point.

For each set I looked for the number of ν_τ CC events per year per 40 kton (fiducial LArTPC detector mass)

ν_τ appearance optimization

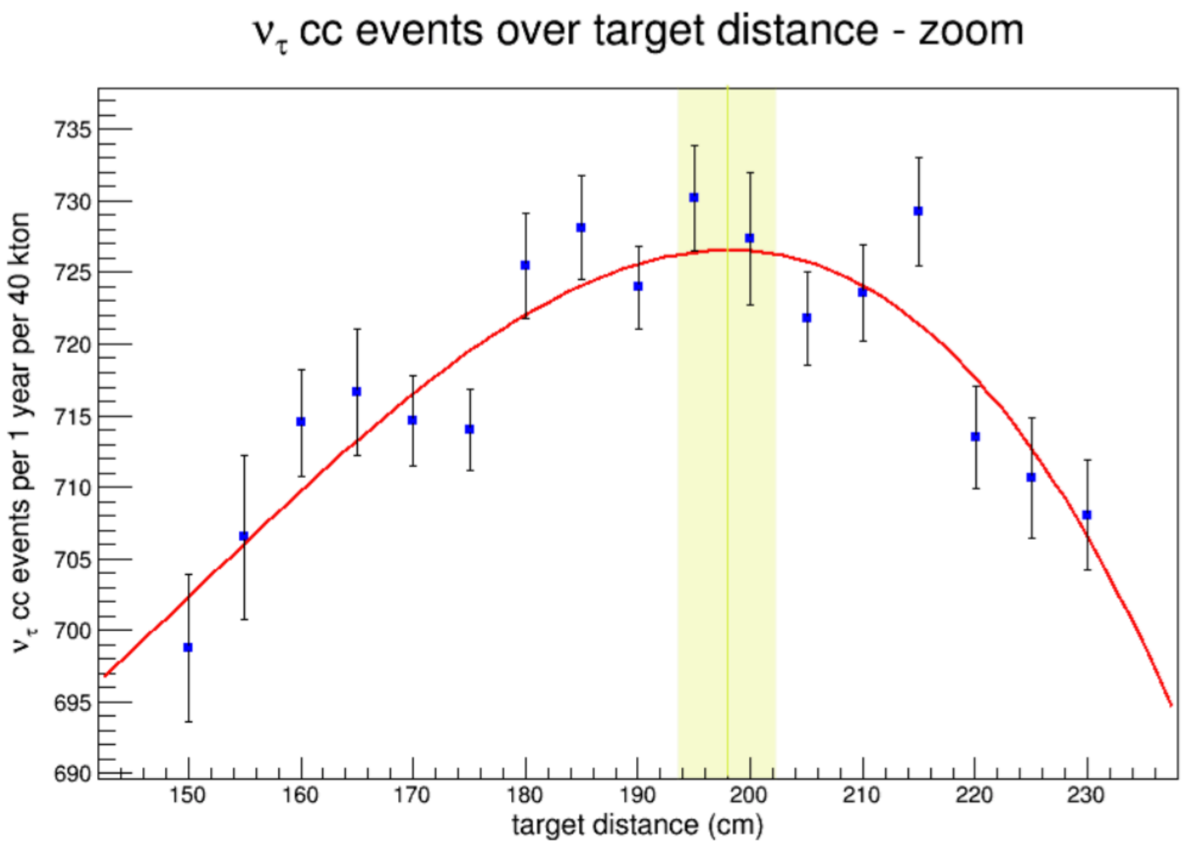
Target and second horn placement



Fermilab

ν_τ appearance optimization

Target and second horn placement



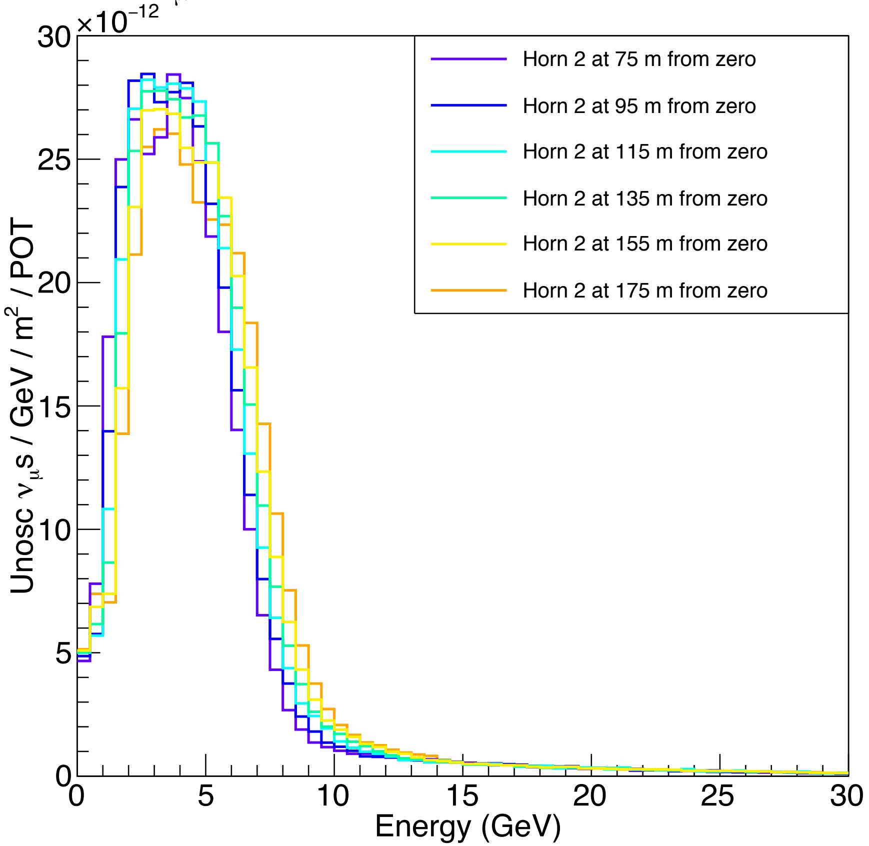
- Horn 2 has to be placed as far as possible (17.5 m)
- The target has to be placed about 2 m far from the horn1 beginning.

ν_τ appearance optimization

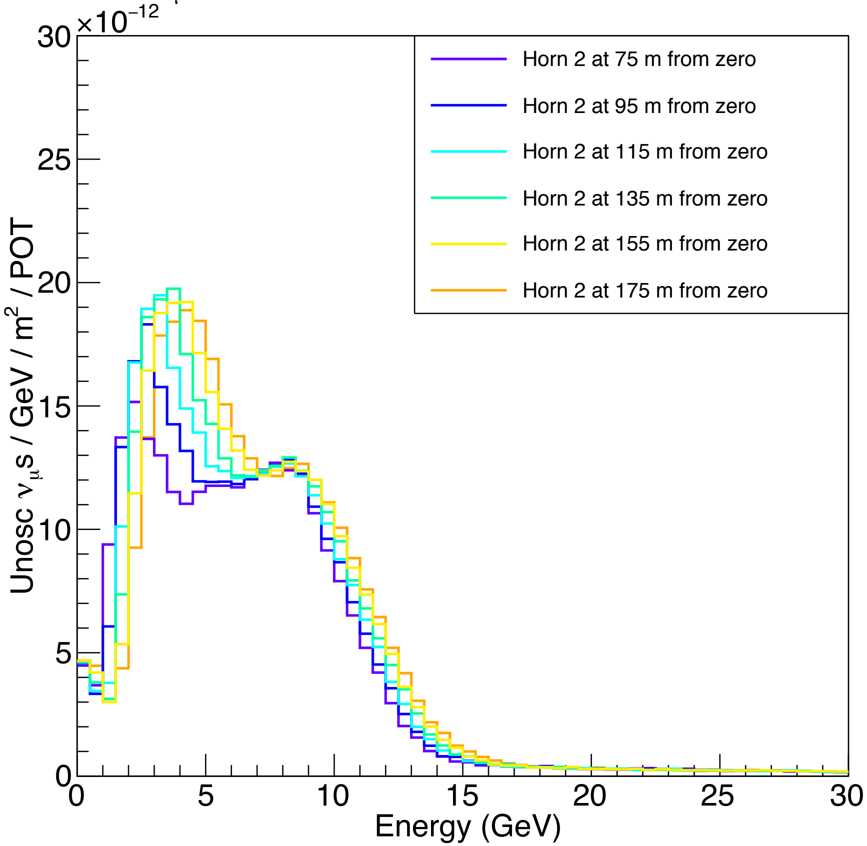
Target and second horn placement

ν_μ fluxes

ν_μ flux - target at 90 cm from zero



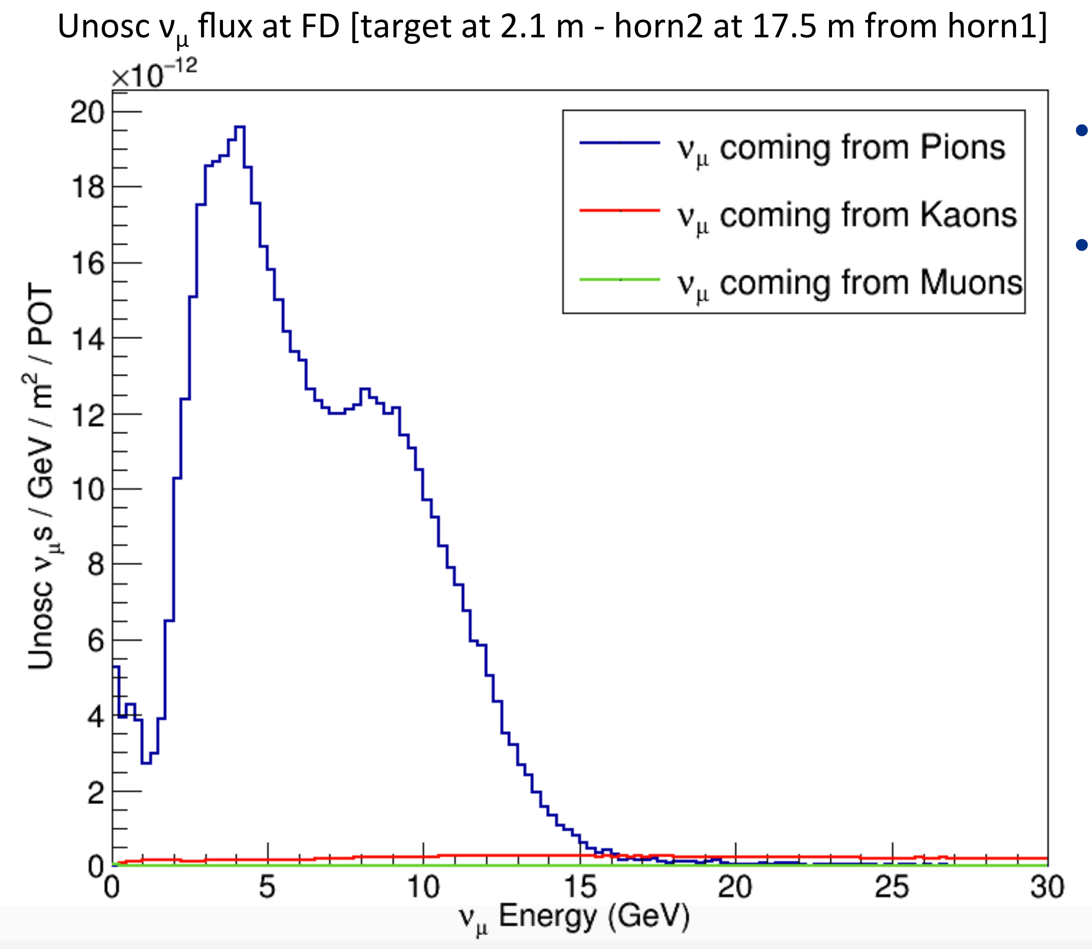
ν_μ flux - target at 210 cm from zero



ν_τ appearance optimization

Target and second horn placement

Neutrino parents: how they contribute to the flux

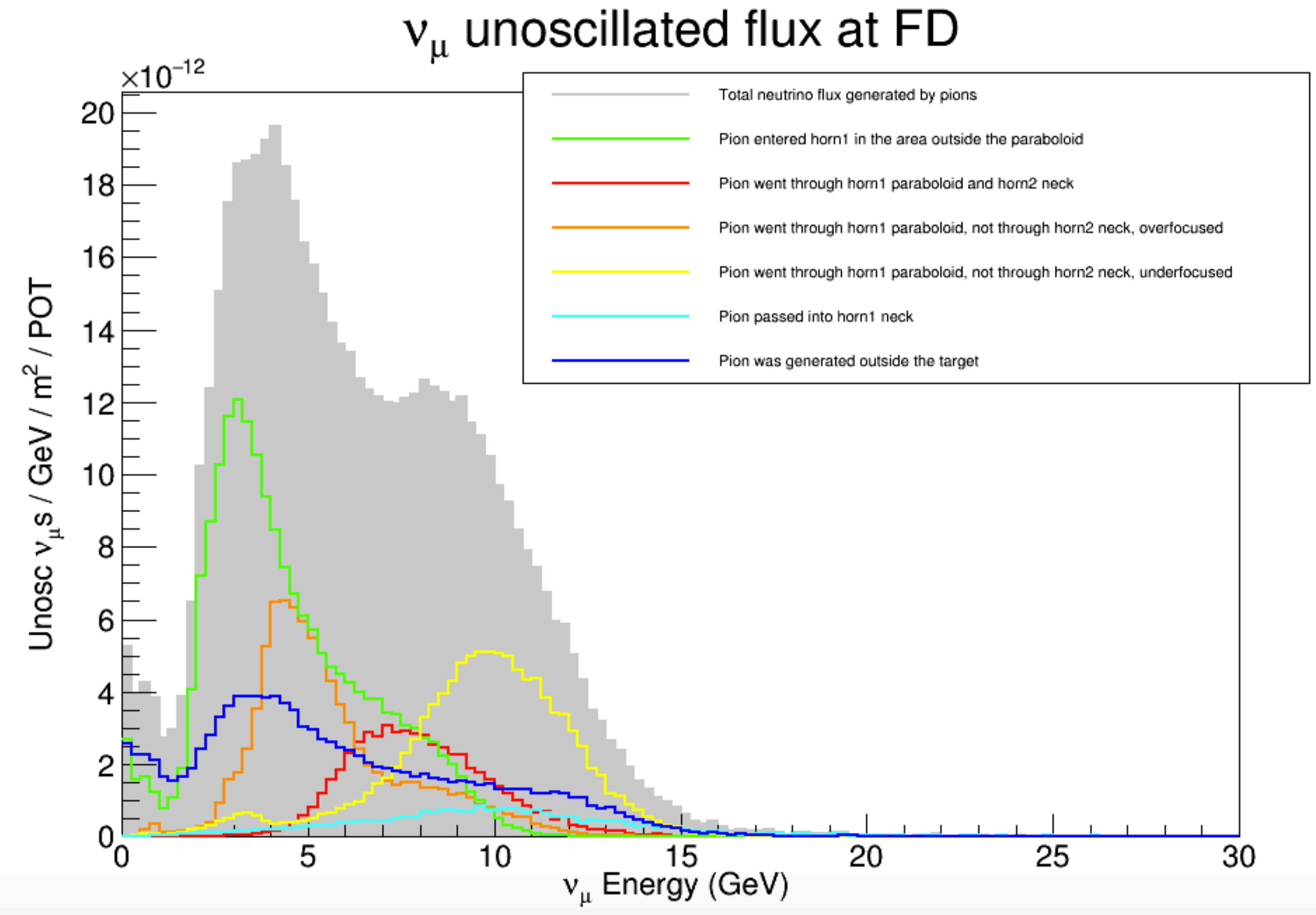


- Almost all neutrinos come from the decay of Pions
- Kaons contribute to the high energy tail of the distribution

ν_τ appearance optimization

Target and second horn placement

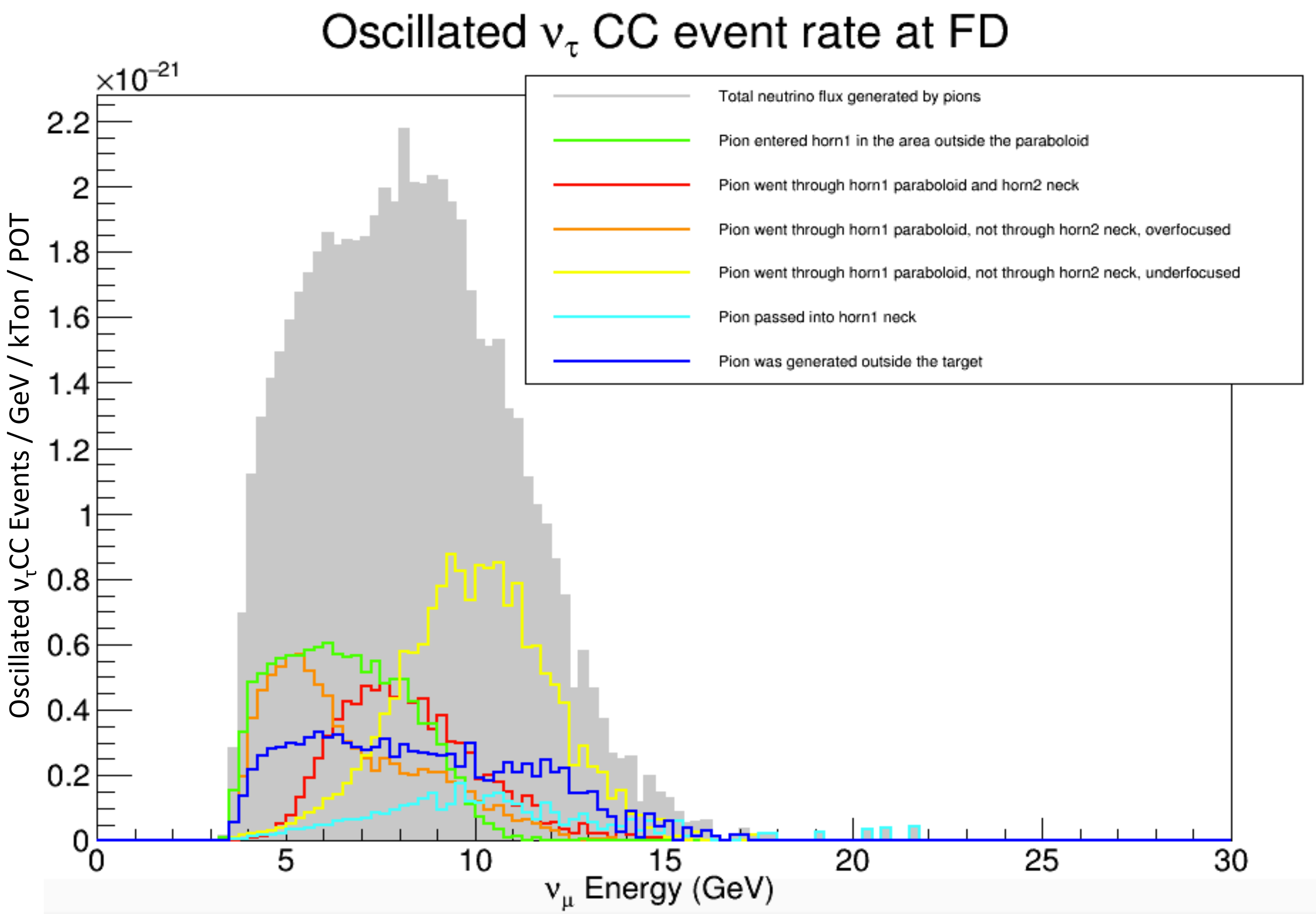
ν_μ fluxes



ν_τ appearance optimization

Target and second horn placement

ν_μ fluxes



ν_τ appearance optimization

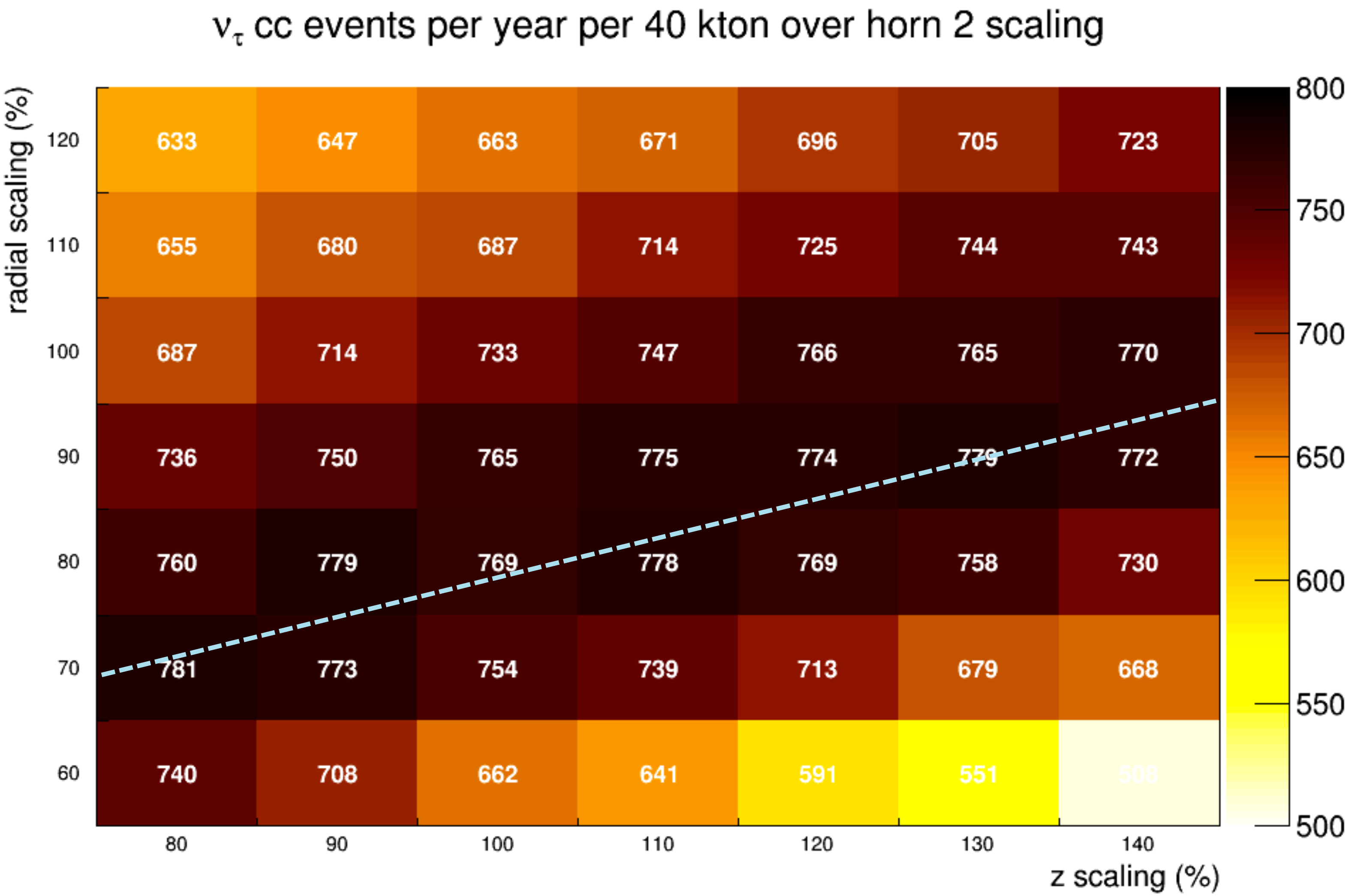
Second horn rescale

Setups for the simulation

- Buffle not installed
- Shield not installed
- Decay pipe snout not installed
- Horns
  - 230 kA current
  - 1.2 MW
- Beam
  - 120 GeV proton momentum
  - Beam sigma = 1.7 mm
- NuMI target
  - Graphite
  - Fin width = 10.0 mm
  - Target length = 1 m
- Target 2 m far from zero
- Second horn 17.5 m far from zero

ν_τ appearance optimization

Second horn rescale



ν_τ appearance optimization

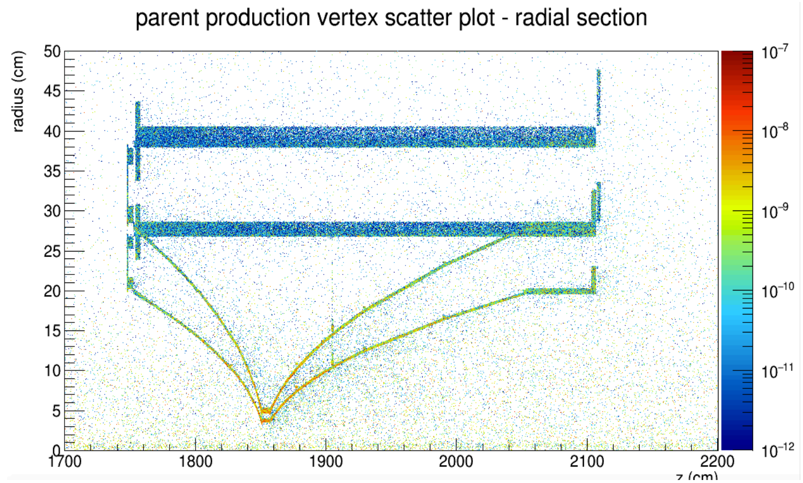
Second horn rescale

Is it better to enlarge horn 2 or to make it smaller?

70% radial scaling
100% longitudinal scaling

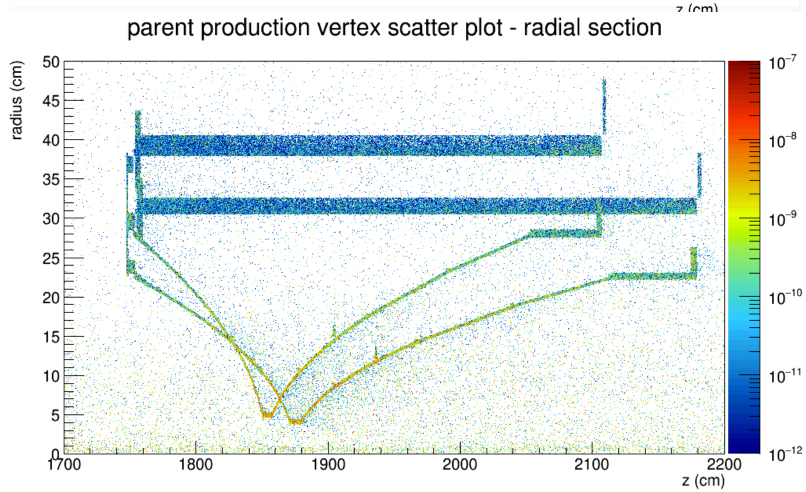
PRO
Cost less ?
CONS
More mechanical stress ?

This configuration will be used for the cylindrical and spherical target simulations



80% radial scaling
120% longitudinal scaling

CONS
It would be necessary to move horn 2 at 16.5 m from horn 1 losing flux

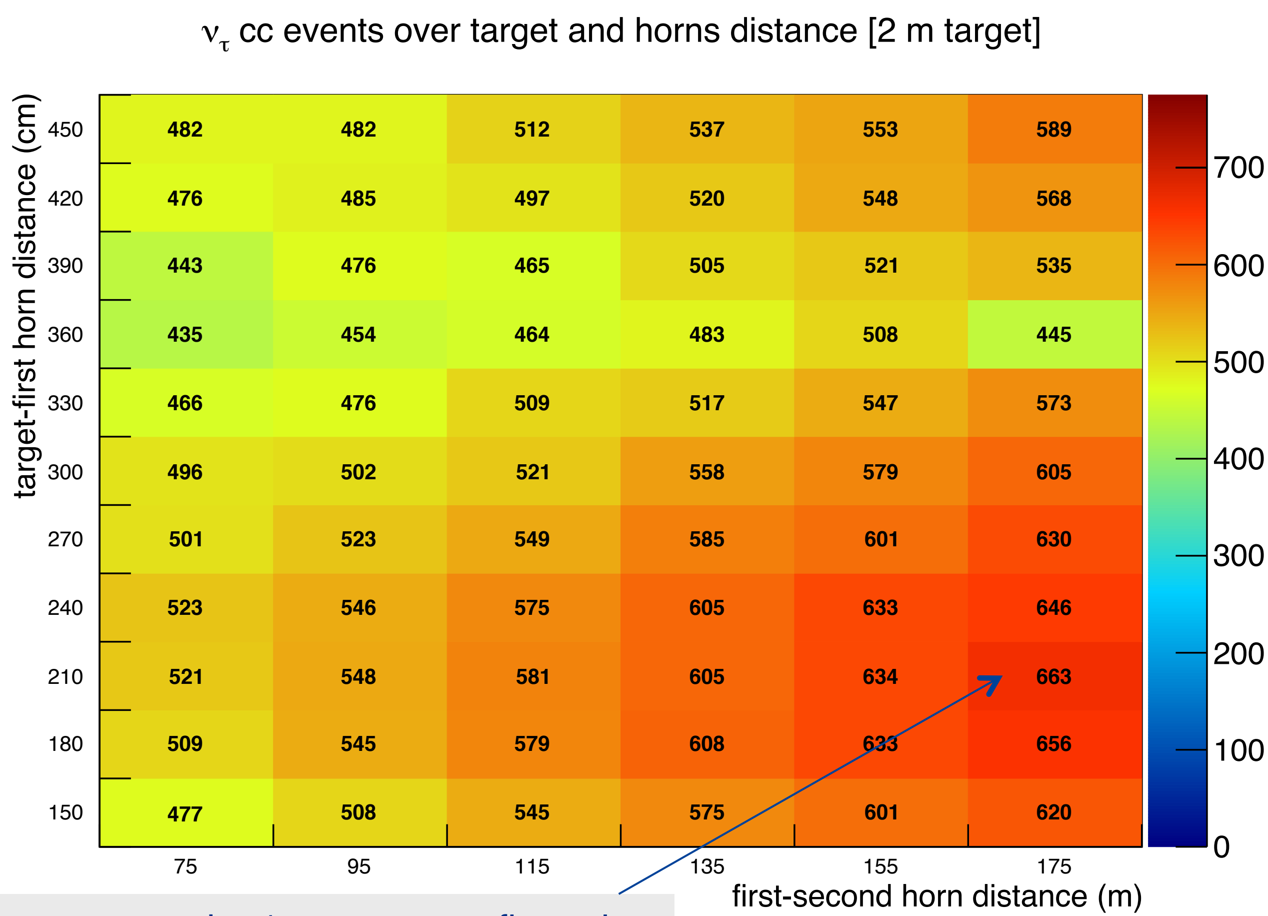


Fermilab

ν_τ appearance optimization

Target optimization

2.0 m long NuMI target



8.5 % less events respect to the 1 m target configuration

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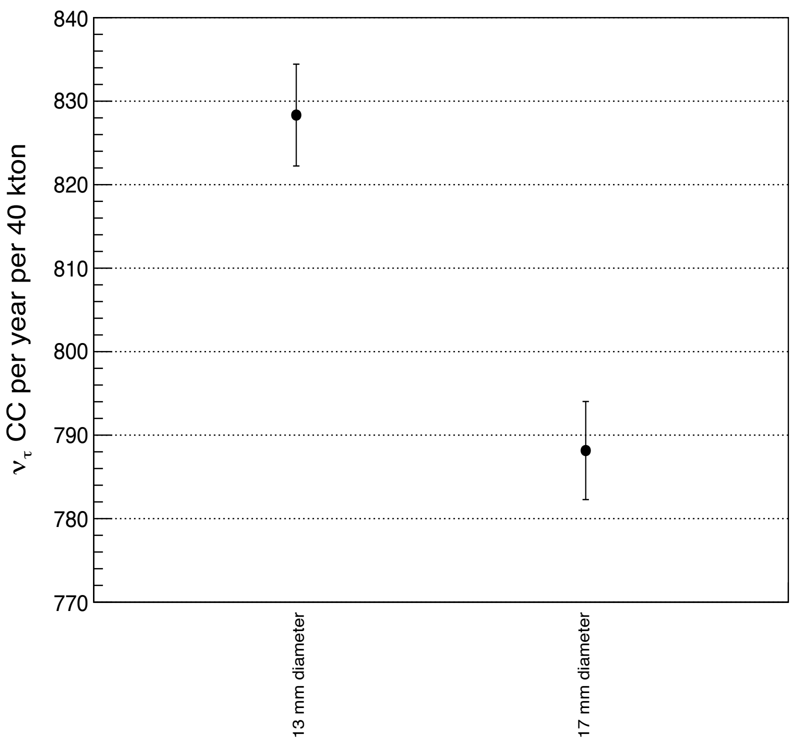
ν_τ appearance optimization

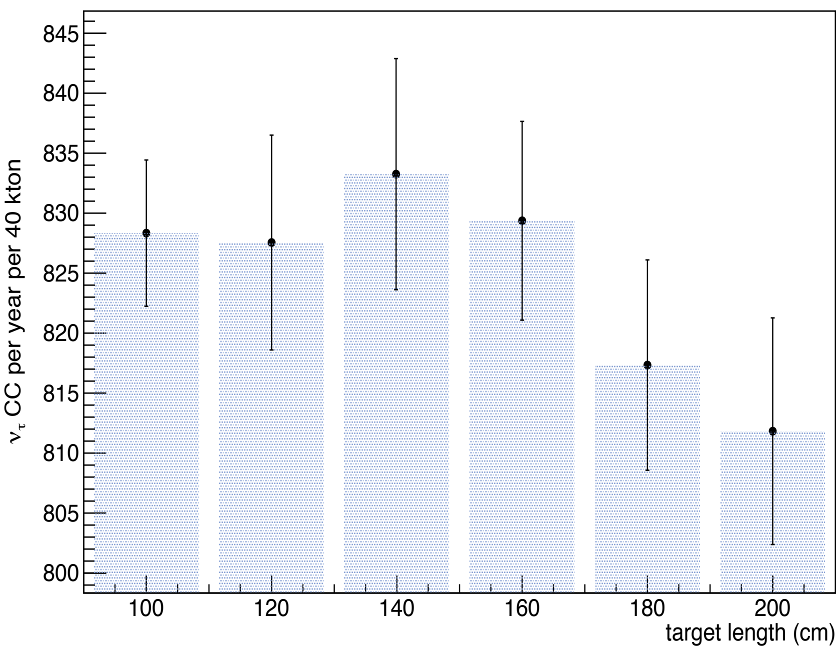
Target optimization

Multi sphere Beryllium target

13 mm vs. 17 mm diameter [1m long target]



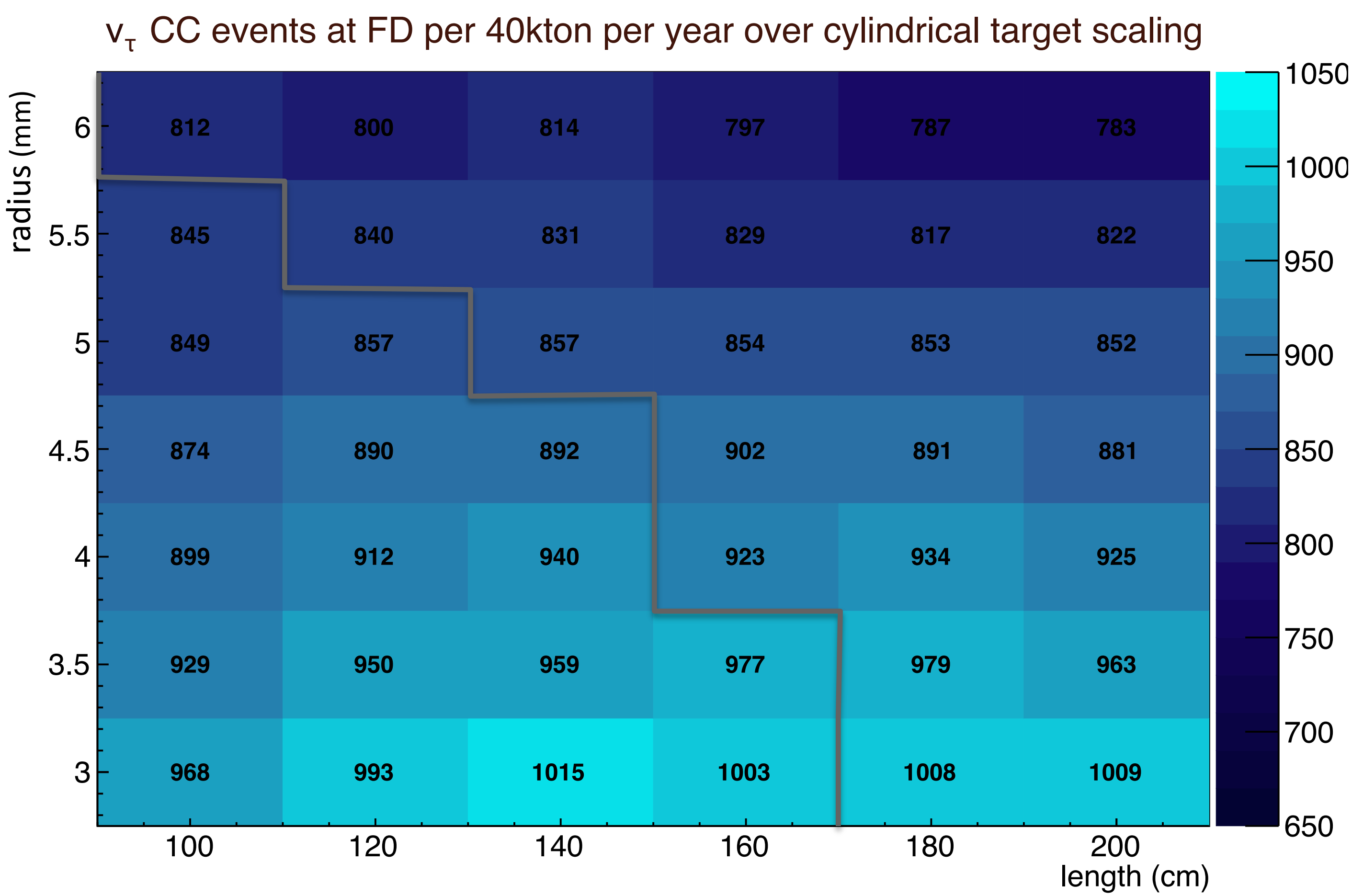
13 mm diameter target – events over target length



ν_τ appearance optimization

Target optimization

Cylindrical simple Graphite target



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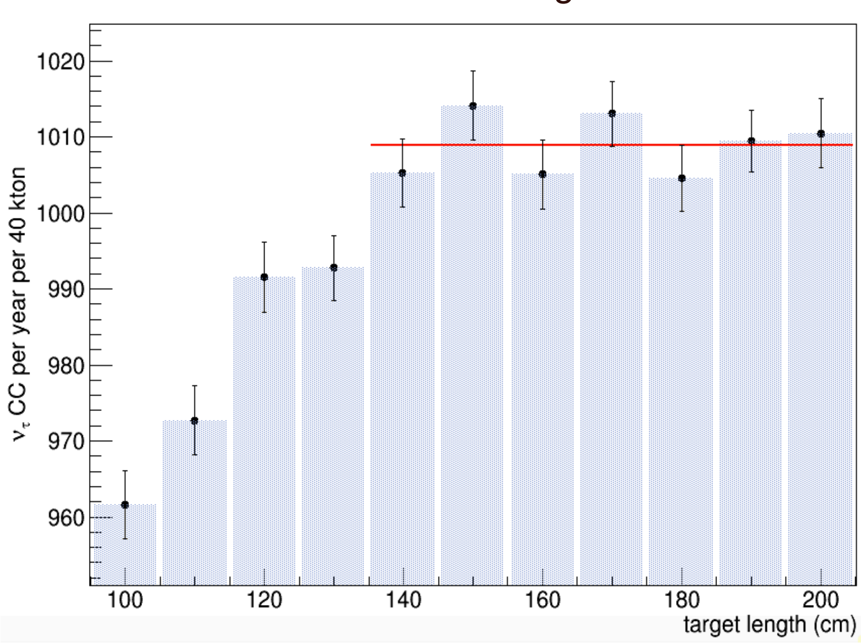
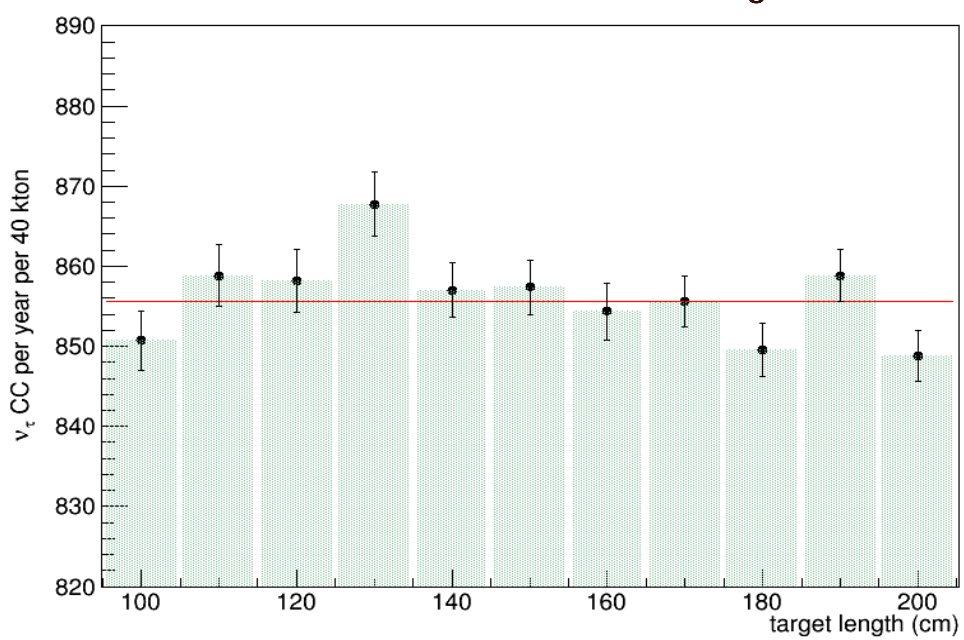
ν_τ appearance optimization

Target optimization

Cylindrical simple Graphite target





Fermilab

Work left to do toward optimization

τ decay channels and signal reconstruction

Neutrino's flavor can be detected only in CC events.
The following table shows the τ decay channels that the detector is able to resolve and their relative branching ratio.

$\tau^- \to \mu^- + \bar{\nu}_\mu + \nu_e$	17.4%
$\tau^- \to e^- + \bar{\nu}_e + \nu_\tau$	17.8%
$\tau^- \to \pi^- + \nu_\tau$	10.8%
$\tau^- \to \pi^- + \pi^0 + \nu_\tau$	25.5%
$\tau^- \to 3\pi(\pi^0)$	15.2%
$total =$	86.7%

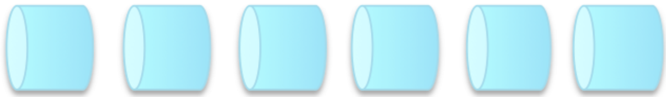
Every decay channel has his own background which has to be evaluated in order to estimate the reconstruction efficiency.

Fermilab

Work left to do toward optimization

1. Try target with lower density

For example a cylindrical target composed by many little cylinders separates by thin layers of air.



2. Using a genetic algorithm

Set parameters near to the ones I found and apply a genetic algorithm to find the very best geometry for the ν_τ appearance.

3. Estimate reconstruction efficiency

Simulate CC events at far detector and evaluate the relevant background for the CC event occurred. Find neutrino energy threshold under whom it is not possible to distinguish the signal from the background.

In LArTPC the reconstruction efficiency can be around 20%;

Conclusions

- The second horn has to be placed as far as possible from the first horn.
- The target has to be placed about 2 m distant from the first horn.
- The second horn has more focusing power if radially rescaled of about 75% (and all proportional configurations).
- A thinner target with low density works better.
- A thinner target can be made longer without reducing (or maybe increasing) the number of events: this is good because longer target means less energy deposited in the absorber.
- I got a maximum of 880 ν_τ CC events per 40 kton per year using a (realistic) cylindrical target with 5 mm of radius and 150 cm of length.
  This means a factor of 4 respect to the reference design and a factor of 8 respect to the optimized three horns design.
- A lot of work has still to be done to
  - find the best geometry,
  - estimate the reconstruction efficiency.

I presented these results twice to the Beam Interface Group during the group meeting.

Thank you