Increased Neutrino Yield with the New NOvA Target Design Simulation Study

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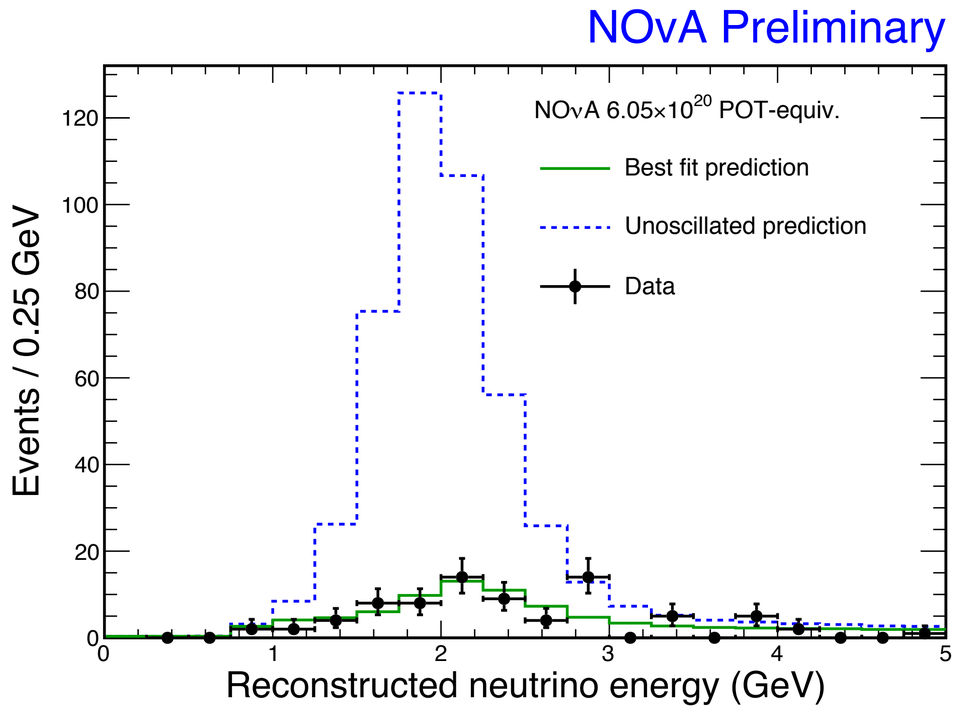
On behalf of NOvA Collaboration

New Perspectives-2017
Fermilab
June 06, 2017

Motivation

- NOvA Far Detector (FD) observed few events with exposure of 6.05 e20 POTs.
- **We need more events, more POTs.**



The **Event yield (N)** for the NuMI off-axis NOvA neutrino experiment is :

$$N \propto (\text{Beam Power})(\text{time})\ (\boxed{\nu \text{ per proton}})\ * M(\varepsilon)$$

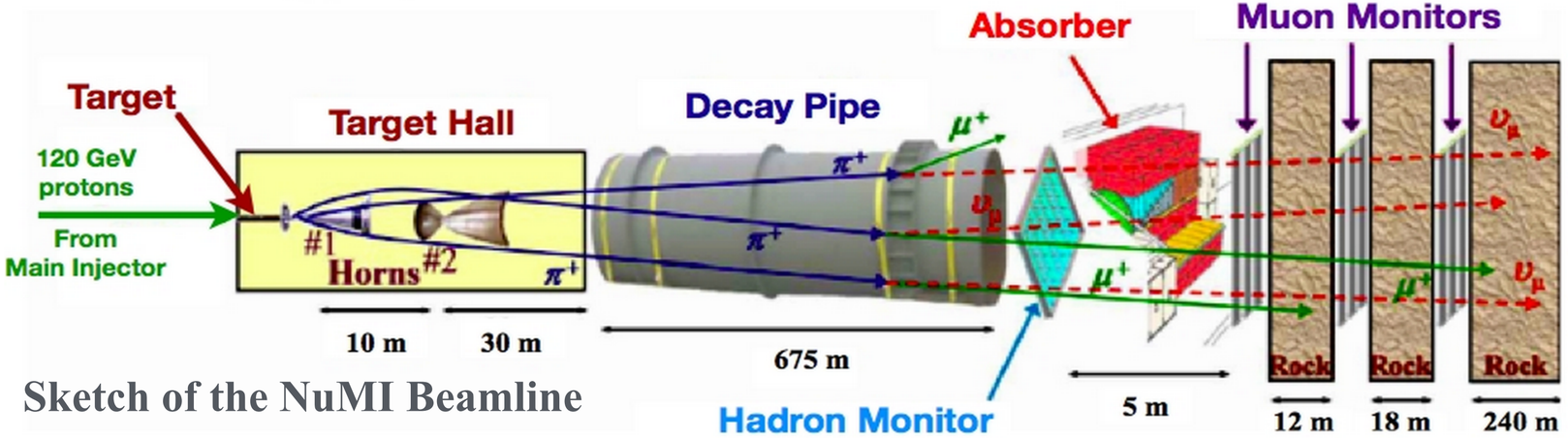
M = Detector mass

ε = Detector efficiency

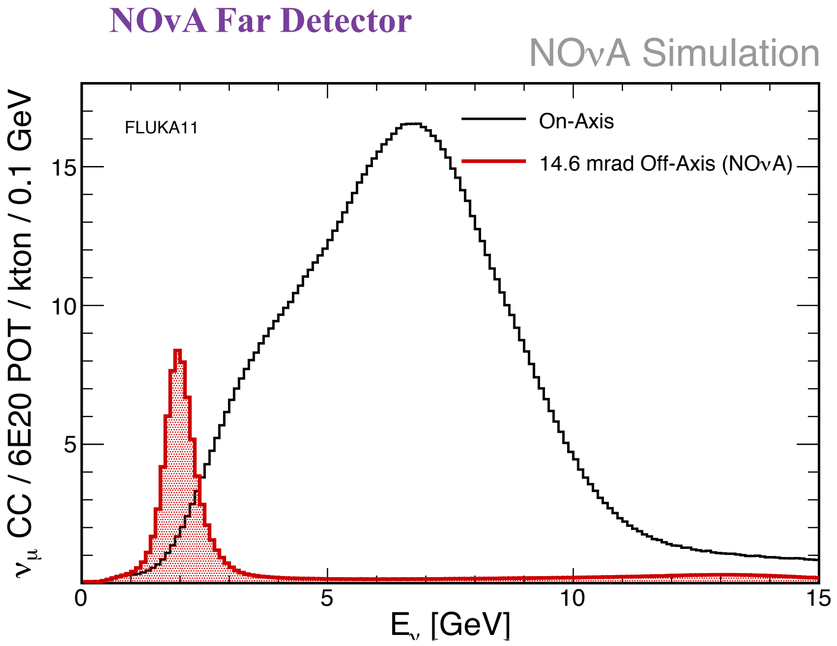
We look for several ways to optimize the **efficiency (ν per proton) of NuMI target and horn system** to produce useful neutrinos for NOvA.

The NuMI (Neutrinos at the Main Injector) Beam Line

- The NOvA detectors use the NuMI beam line to get an almost pure ν_μ beam.



Sketch of the NuMI Beamline

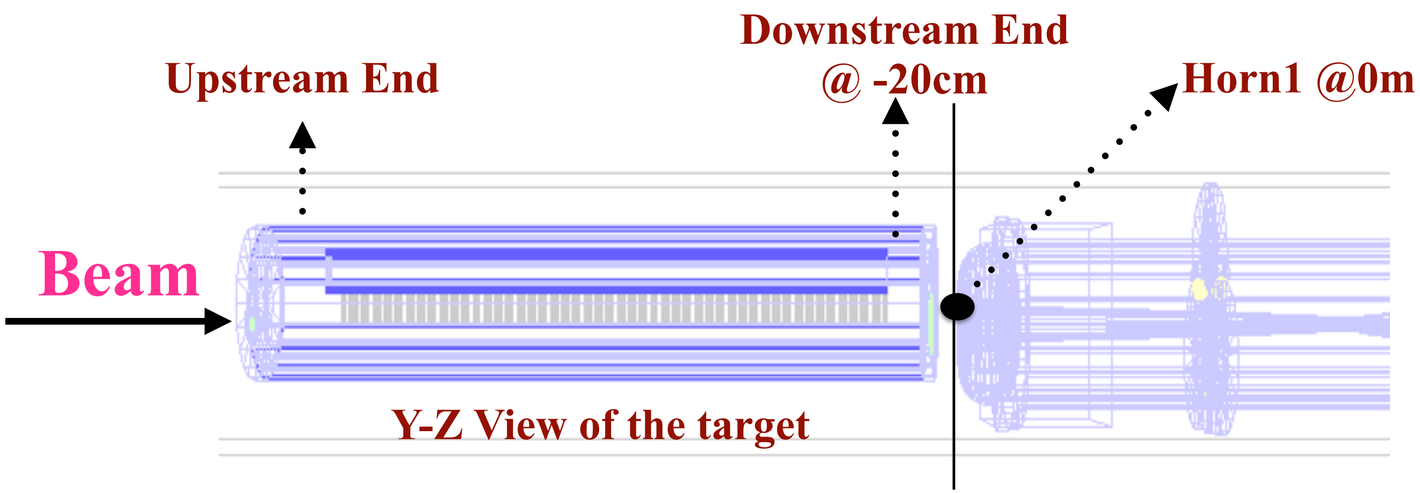


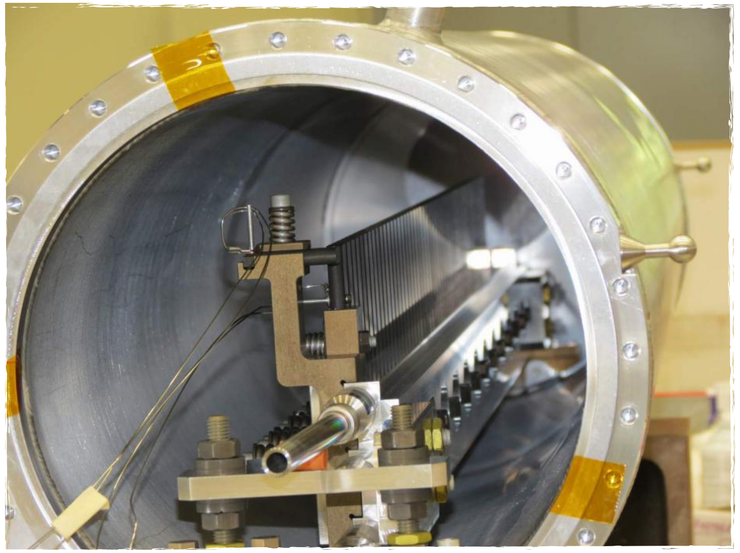
- **Target:** 120 GeV proton beam from MI interacts with graphite target & produce short-lived particles e.g pions & kaons.
- **Magnetic Horns:** To focus the secondary particles with two magnetic horns.
- **Decay Pipe:** Secondaries decay to produce ν_μ in He filled decay pipe.

The NOvA off-axis position selects quasi mono energetic <u>neutrino beam of 2 GeV to have the highest probability of oscillation at the FD</u> 810 km away in Northern Minnesota.

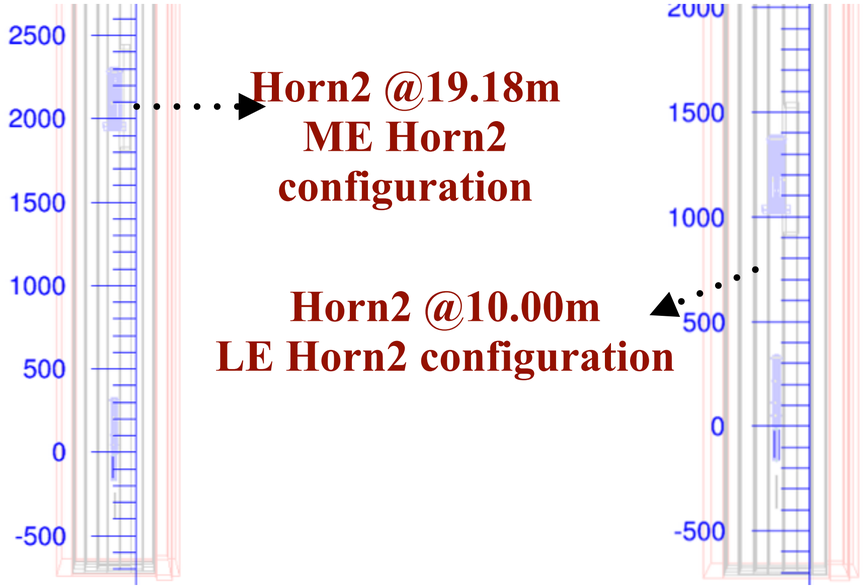
NuMI target and horn system for NOvA

- The NOvA target consists of 48 graphite fins (+2 budal monitors) with a total target length of 1.2m.
- The downstream end of the NOvA target is placed at -20 cm (outside the Horn1) w.r.t to the Horn1.





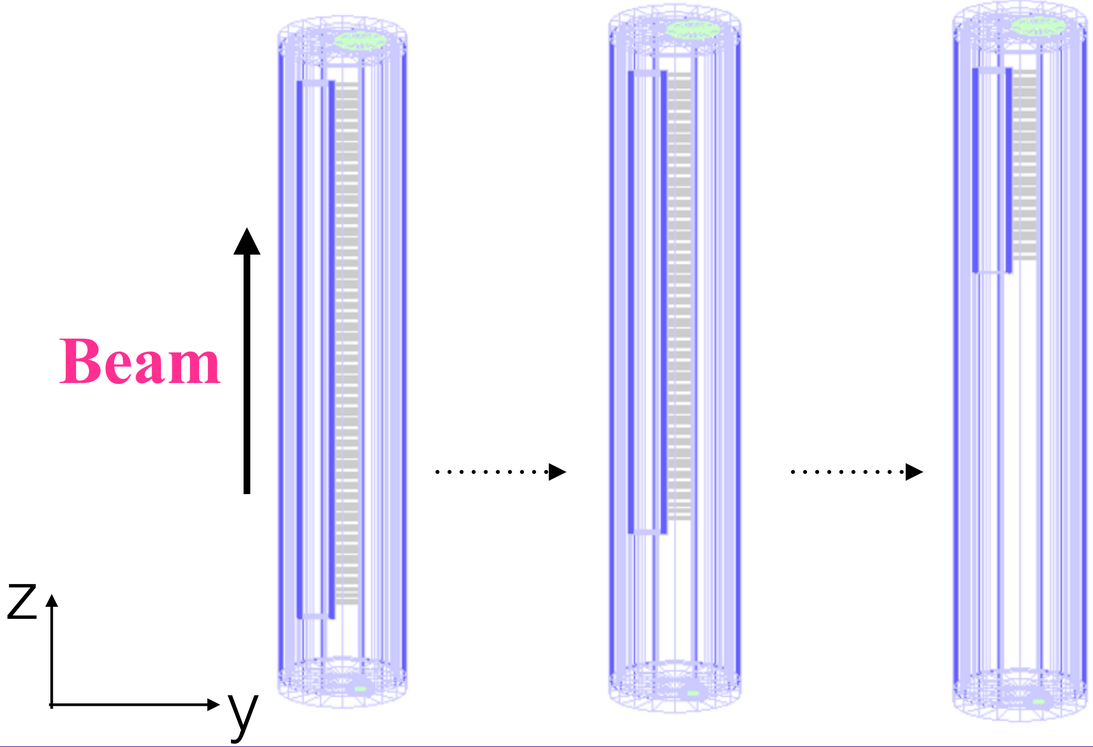
The NOvA Target



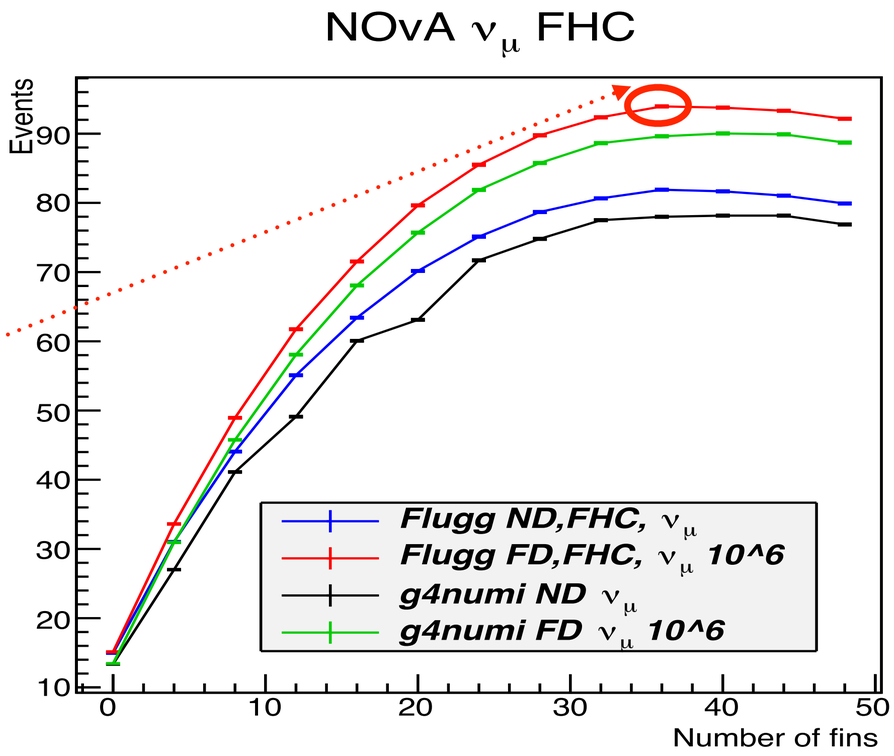
- **<u>Medium Energy Horn2 configuration (ME):</u>** The Horn2 is at 19.18m w.r.t the Horn1: *standard configuration for NOvA.*
- **<u>Low Energy Horn2 configuration (LE):</u>** The Horn2 is at 10.0m w.r.t the Horn1: *used in past by MINOS On-Axis Experiment.*

Study of neutrino yield

- Longer targets & targets with gaps : observed fewer ν_μ events.
- Reduce the number of fins from the upstream part of the NOvA target, making a shorter target : observed maximum ν_μ yield with 36-fins target.



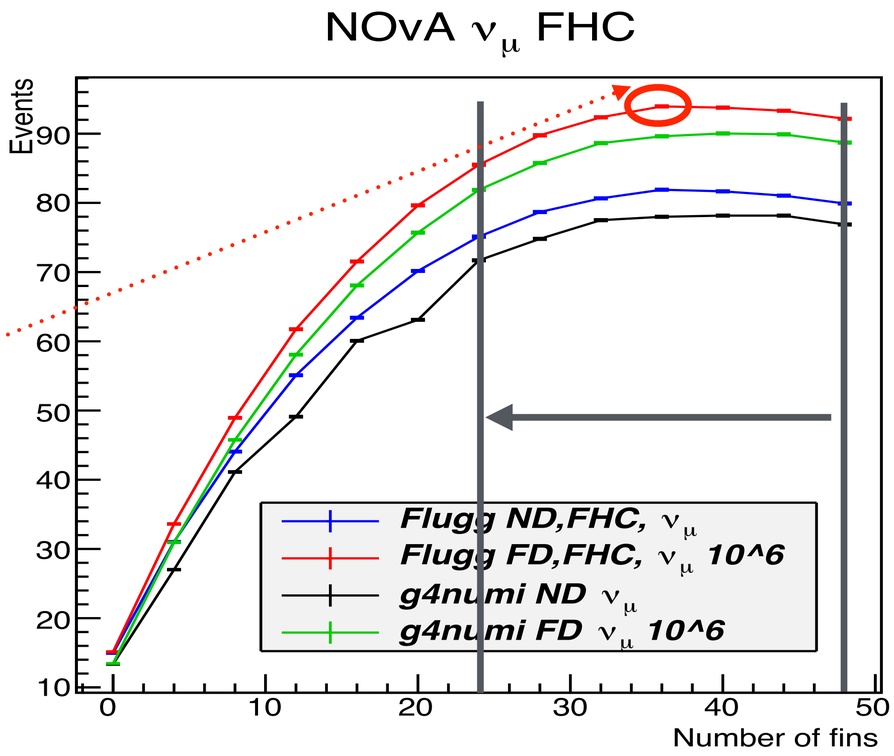
YZ view of the target



Events are in 1-3 GeV Energy Range
FLUGG & G4NuMI Simulations

Study of neutrino yield

- Longer targets & targets with gaps : observed fewer ν_μ events.
- Reduce the number of fins from the upstream part of the NOvA target, making a shorter target : observed maximum ν_μ yield with 36-fins target.
- Using half of the target (24 fins), ***neutrino flux is reduced by just 5% at the FD*** as compared to the whole 48 fins target.
- **The number of protons** surviving a 24 fins target (λ ~1.25) is **~30% : WASTE of protons!**



Events are in 1-3 GeV Energy Range
FLUGG & G4NuMI Simulations

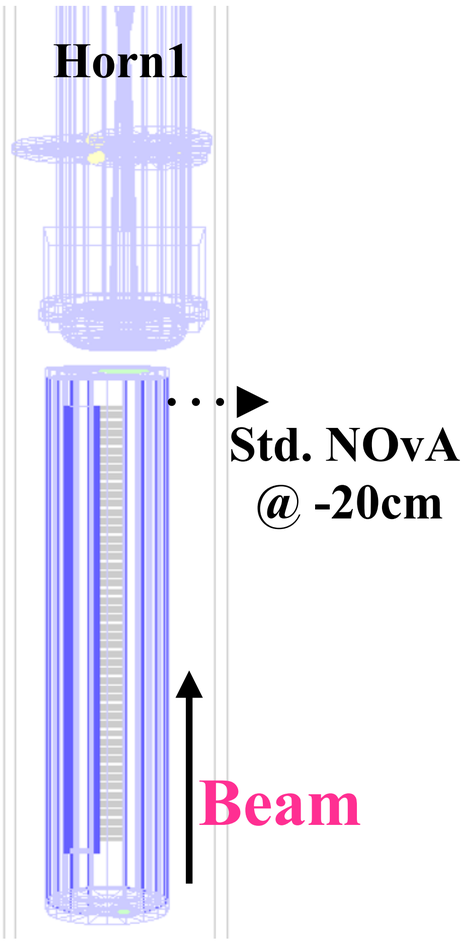
Idea is to use these protons elsewhere to get the increased neutrino yield and it can be achieved by extending the target inside the Horn1!!

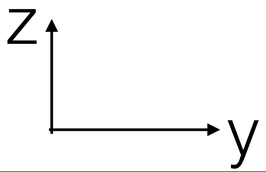
Target Specification (Y-Z View)

Standard NOvA target

	2+48 Fins (Graphite)
Length	24 mm
Width	7.4 mm
Height	63 mm
Pitch	0.5 mm

- With cooling tubes only on bottom
- With supporting structure (pressing plates, cooling plates)





Target Specification (Y-Z View)

Standard NOvA target

	2+48 Fins (Graphite)
Length	24 mm
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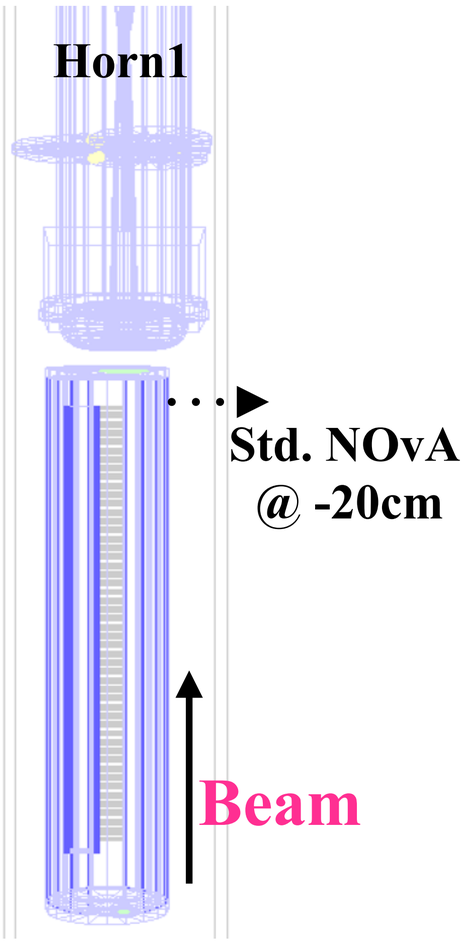
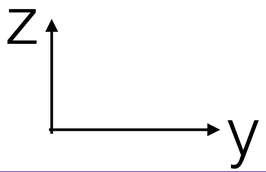
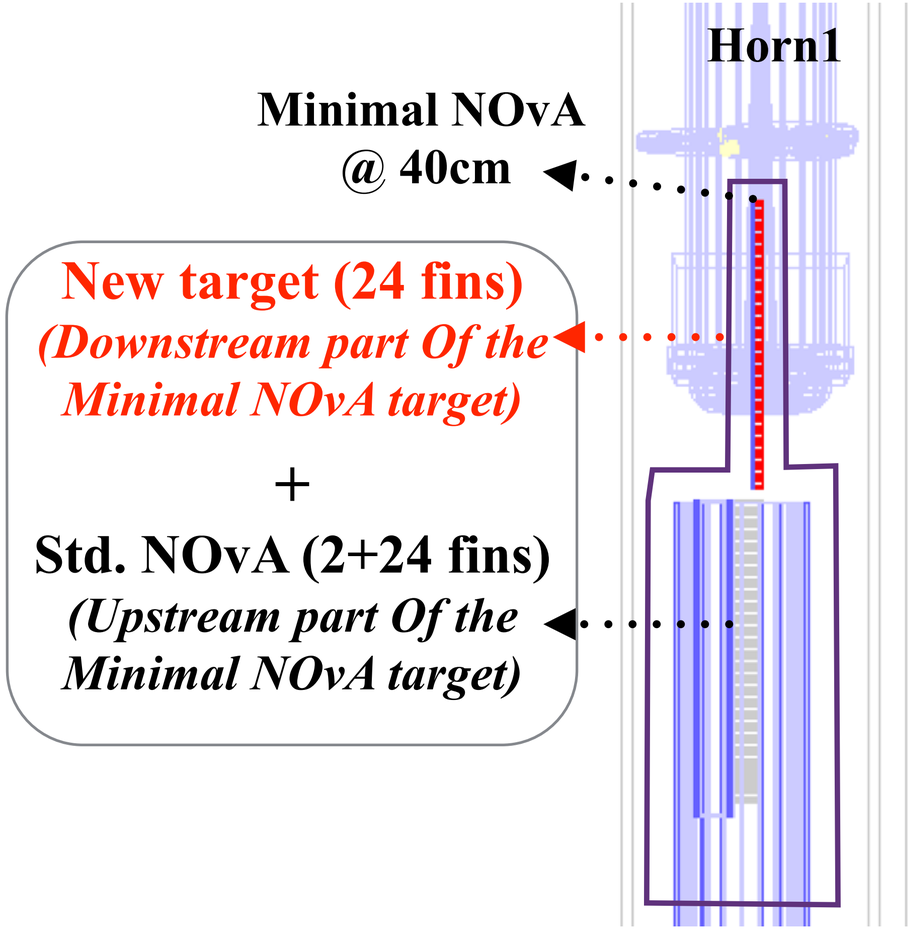




New NOvA target "Minimal NOvA"

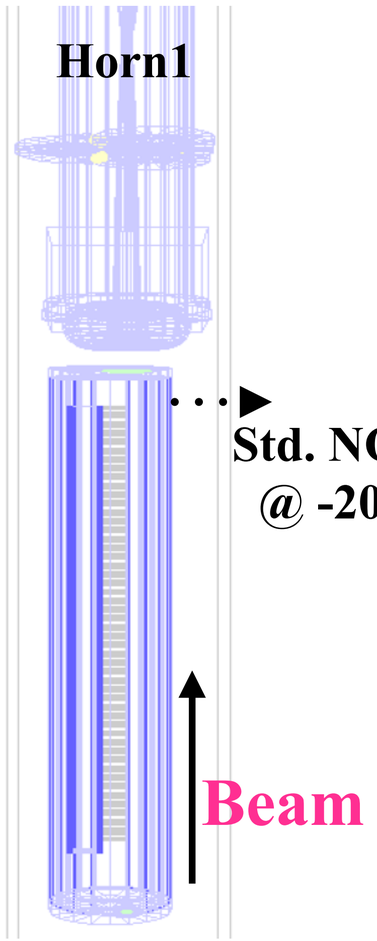


Target Specification (Y-Z View)

Standard NOvA target

	2+48 Fins (Graphite)
Length	24 mm
Width	7.4 mm
Height	63 mm
Pitch	0.5 mm

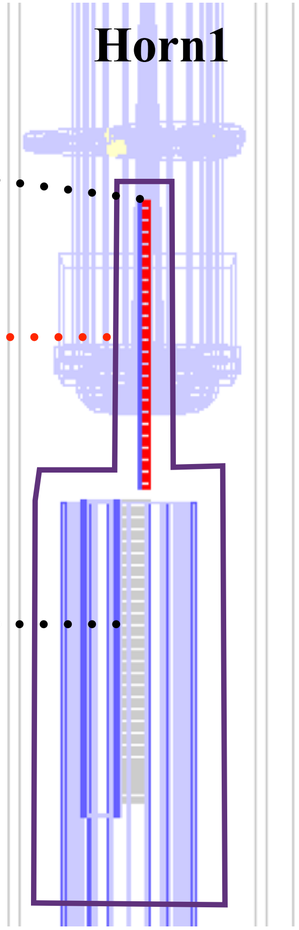
- With cooling tubes only on bottom
- With supporting structure (pressing plates, cooling plates)

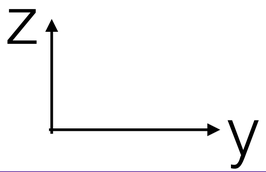


	24 New
Length	24 mm
Width	7.4 mm
Height	17 mm
Pitch	0.5 mm

	2+24 Std.
Length	24 mm
Width	7.4 mm
Height	63 mm
Pitch	0.5 mm

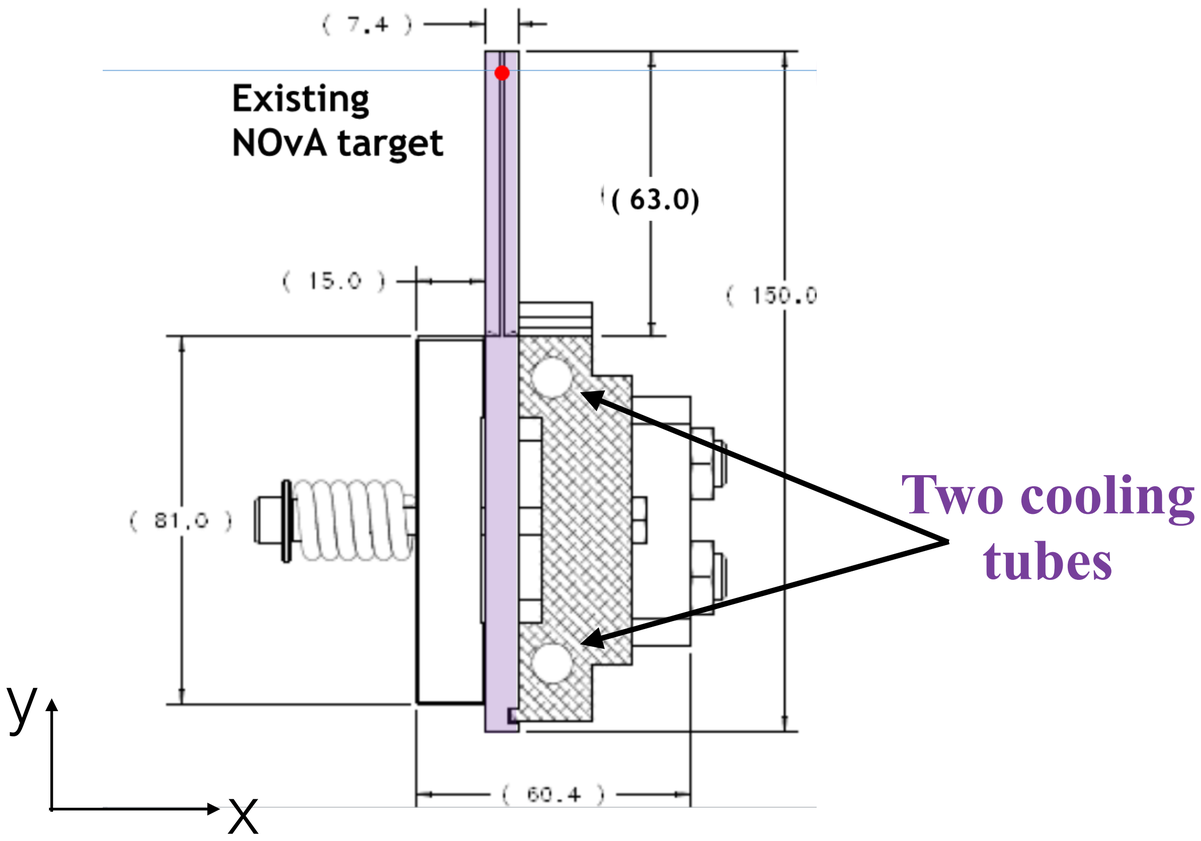
New NOvA target





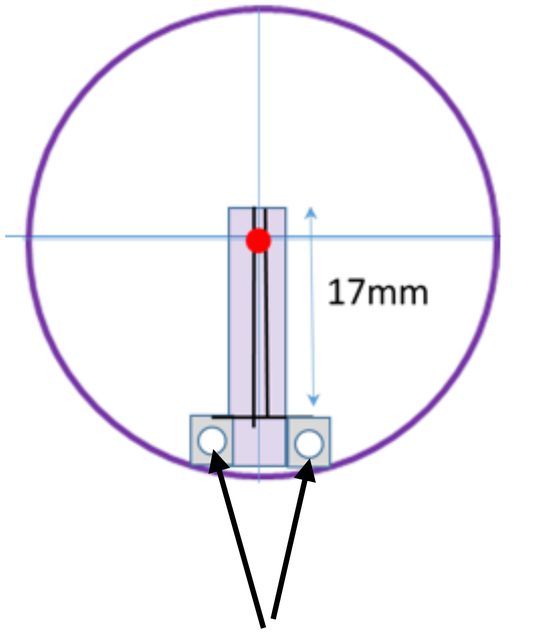
Target Specification (X-Y/ Beam View)

Standard NOvA Target



- With cooling tubes only on bottom
- With supporting structure (pressing plates, cooling plates)

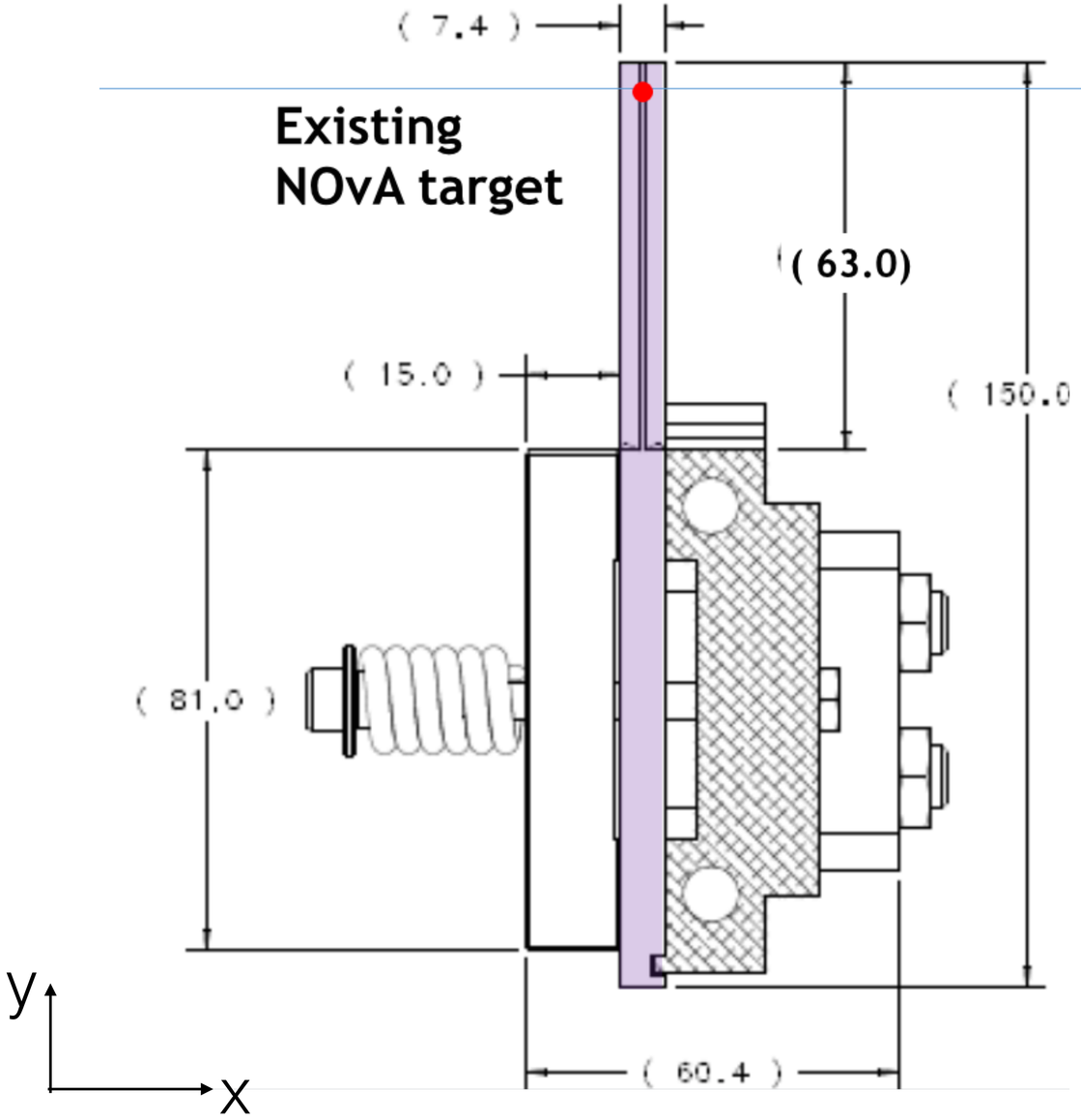
New Target



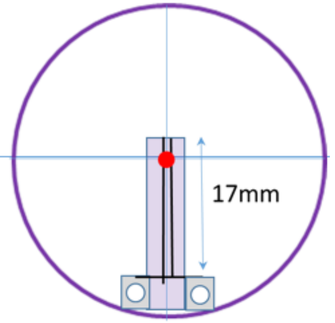
- With cooling tubes far away from the target fin.
- With supporting structure (pressing plates, cooling plates)

Target X-Y/ Beam View (Same Scale)

Standard NOvA Target



New Target



- The new NOvA Target is a concept which requires an engineering study from the Accelerator Division.
- The cooling in the New Target is very minimal.
- Keeping the beam spot on the fins as far as possible from the cooling structure should be the main design goal.

New NOvA target (Minimal NOvA) simulation using FLUGG

Minimal NOvA target (@+40 cm inside the Horn1)

Graphite fins

- **ME Horn2 Configuration (Horn2 @19.18m) *FHC & RHC**
- **LE Horn2 Configuration (Horn2 @10.0m) *FHC & RHC**

Beryllium fins

- **ME Horn2 Configuration (Horn2 @19.18m) *FHC & RHC**
- **LE Horn2 Configuration (Horn2 @10.0m) *FHC & RHC**

Compare these results with the **Std. NOvA target**

**FHC: Forward Horn Current, 200kA (focusing π^+)*

**RHC: Reverse Horn Current, -200kA (focusing π^-)*

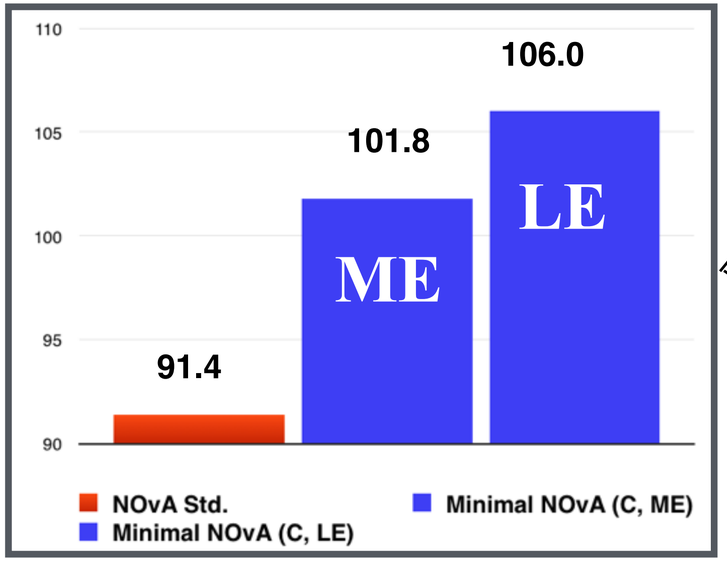
Results: Std. NOvA & *graphite fins* Minimal NOvA target

(FHC)

Red: *Standard NOvA*

Blue: Graphite (C) Fins Minimal NOvA Target

FD Events are in 1-3 GeV Energy range

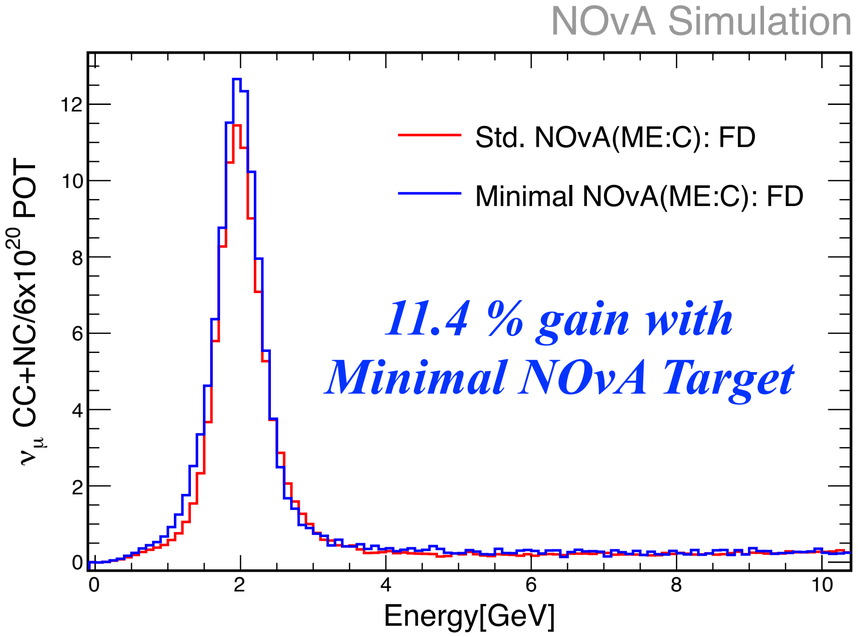


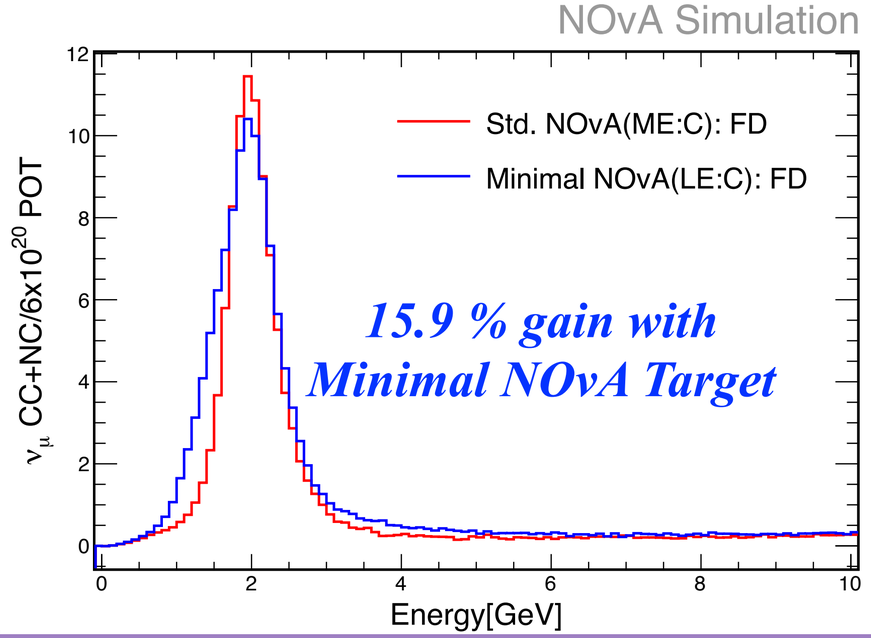
Note: **Y-axis starts from 90** not from 0

ME Horn2 configuration
Horn2 @19.18m

LE Horn2 configuration
Horn2 @10.0m

% is w.r.t Std.NOvA





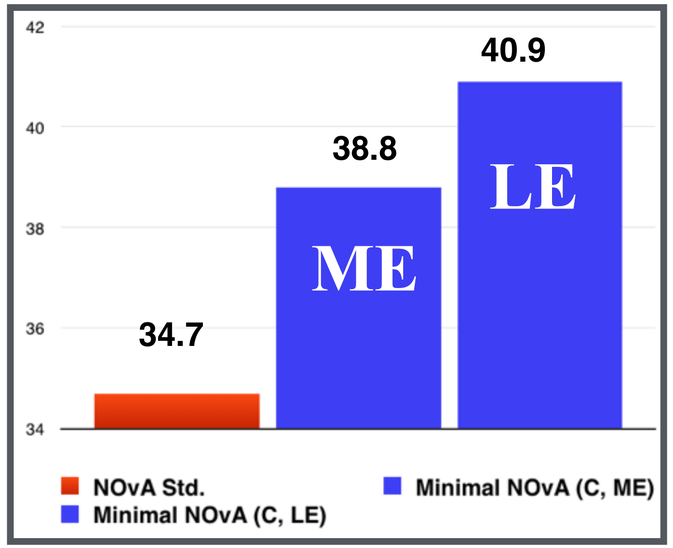
Results: Std. NOvA & *graphite fins* Minimal NOvA target

(RHC)

Red: *Standard NOvA*

Blue: Graphite (C) Fins Minimal NOvA Target

FD Events are in 1-3 GeV Energy range

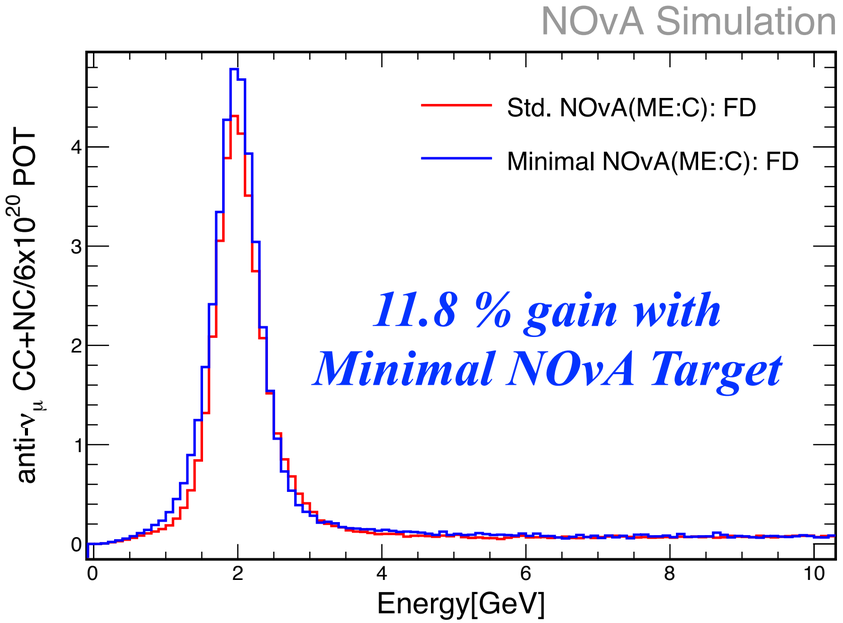


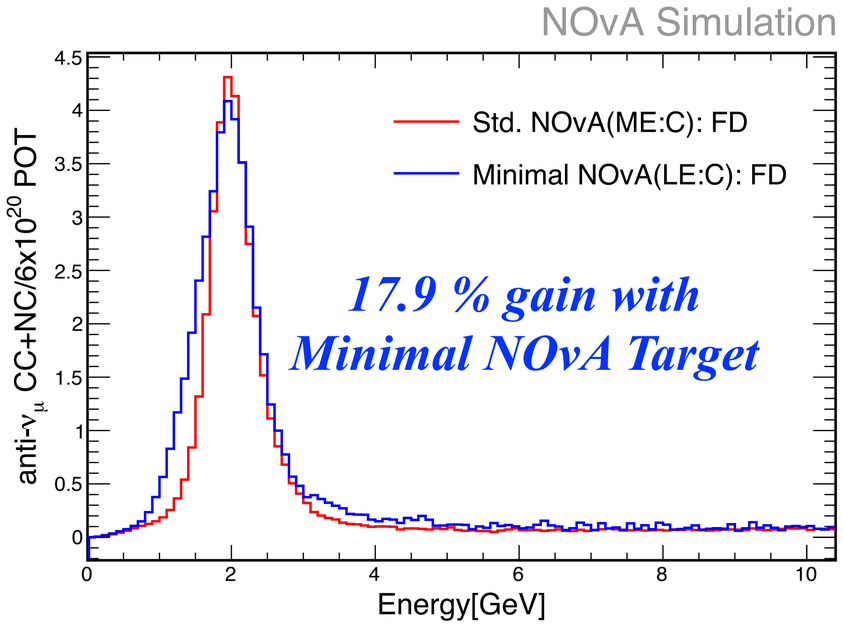
Note: **Y-axis starts from 34** not from 0

ME Horn2 configuration
Horn2 @19.18m

LE Horn2 configuration
Horn2 @10.0m

% is w.r.t Std.NOvA





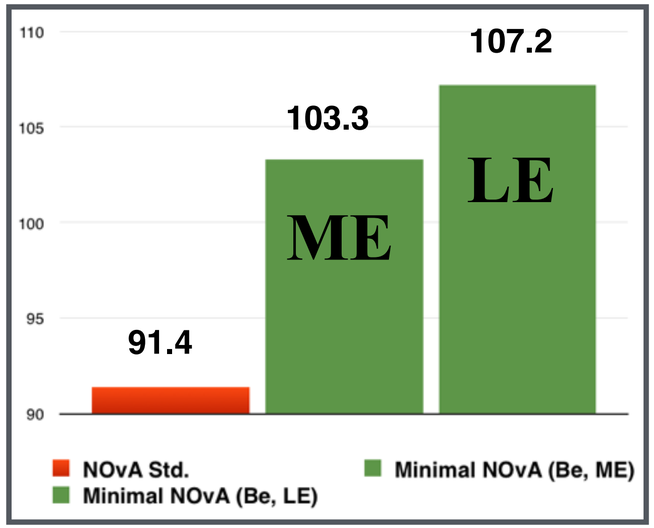
Results: Std. NOvA & *Be fins* Minimal NOvA target

(FHC)

Red: *Standard NOvA*

Green: Be Fins Minimal NOvA Target

FD Events are in 1-3 GeV Energy range



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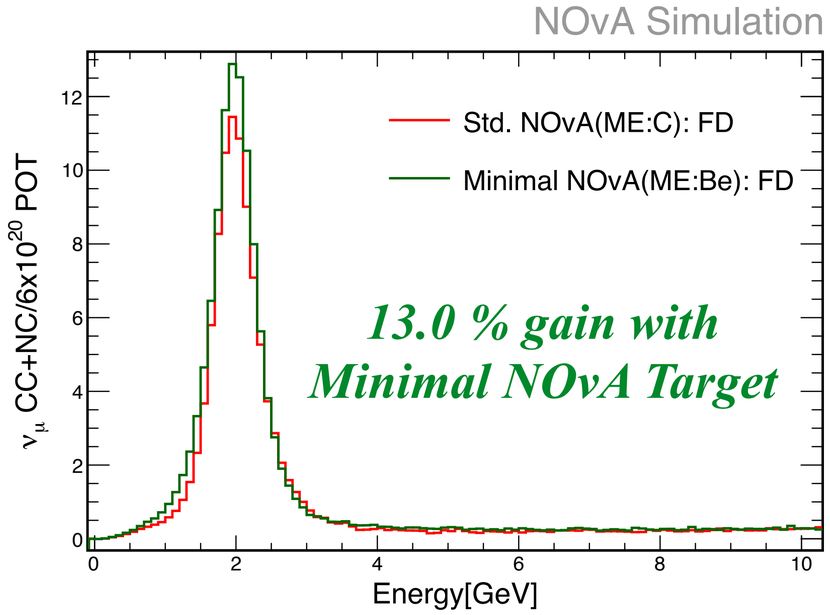
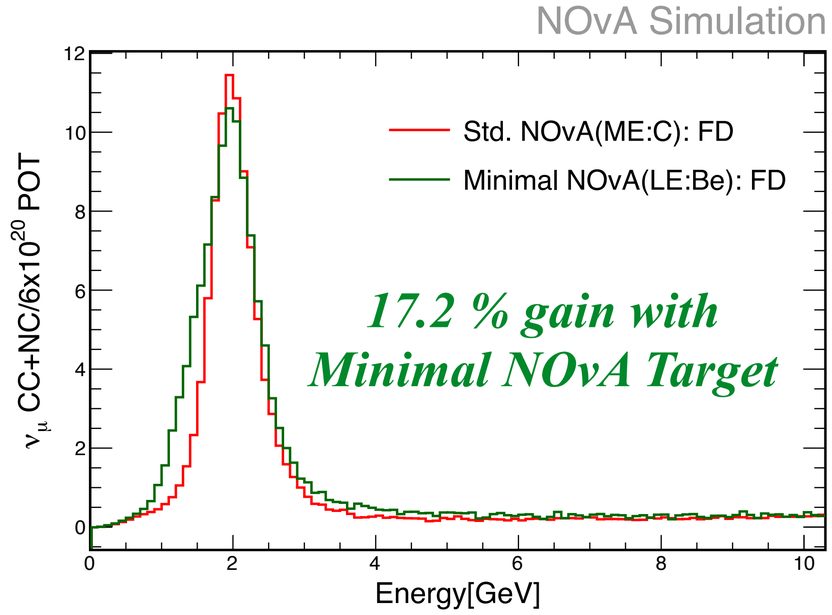
ME Horn2 configuration
Horn2 @19.18m

LE Horn2 configuration
Horn2 @10.0m

% is w.r.t Std.NOvA





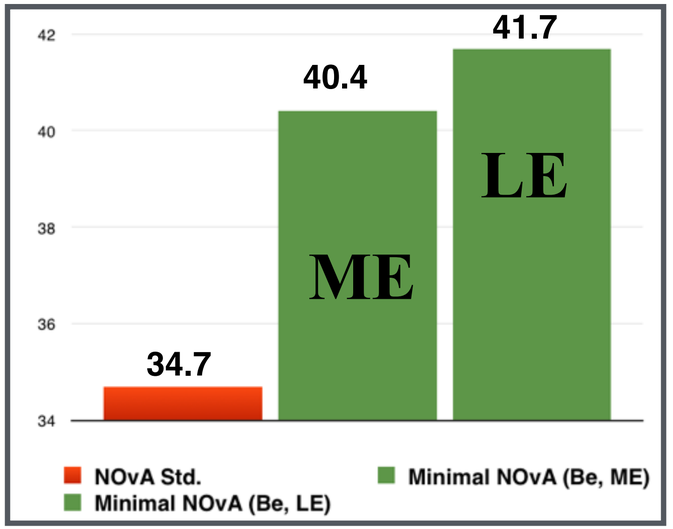
Results: Std. NOvA & *Be fins* Minimal NOvA target

(RHC)

Red: *Standard NOvA*

Green: Be Fins Minimal NOvA Target

FD Events are in 1-3 GeV Energy range

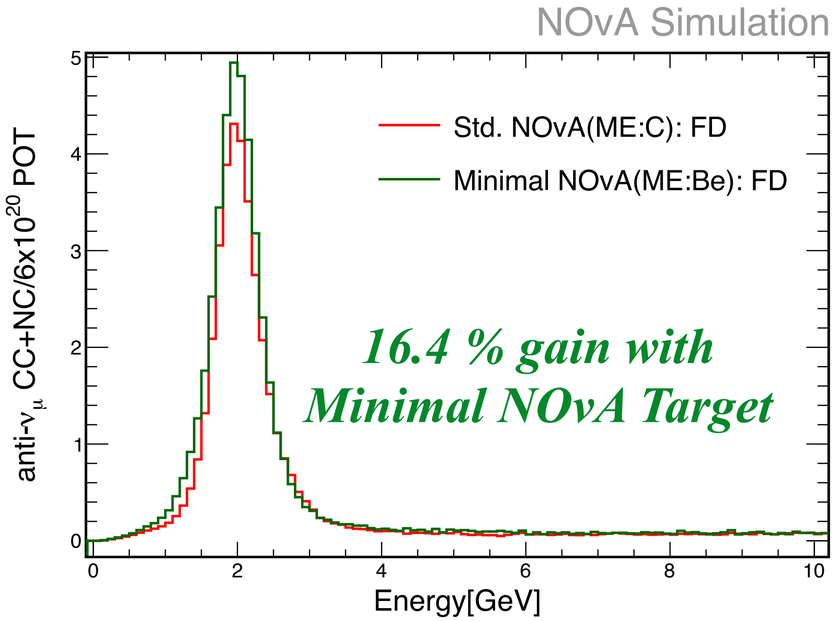


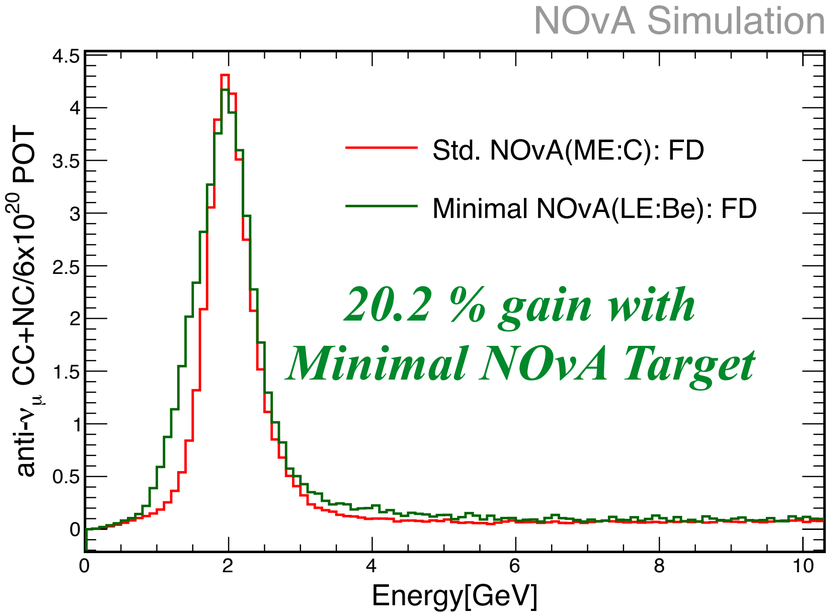
Note: **Y-axis starts from 34** not from 0

ME Horn2 configuration
Horn2 @19.18m

LE Horn2 configuration
Horn2 @10.0m

% is w.r.t Std.NOvA

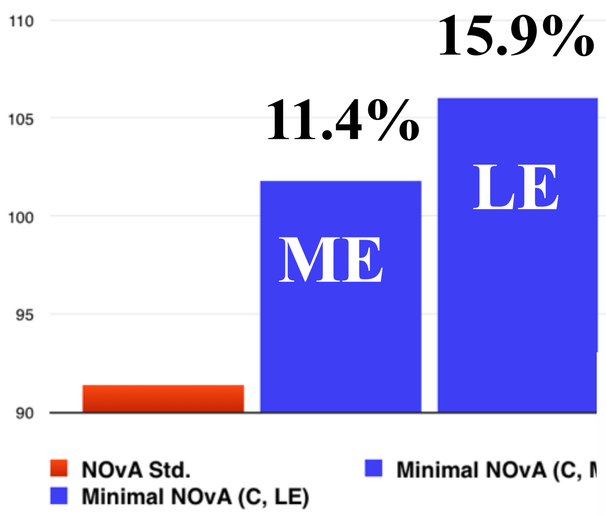




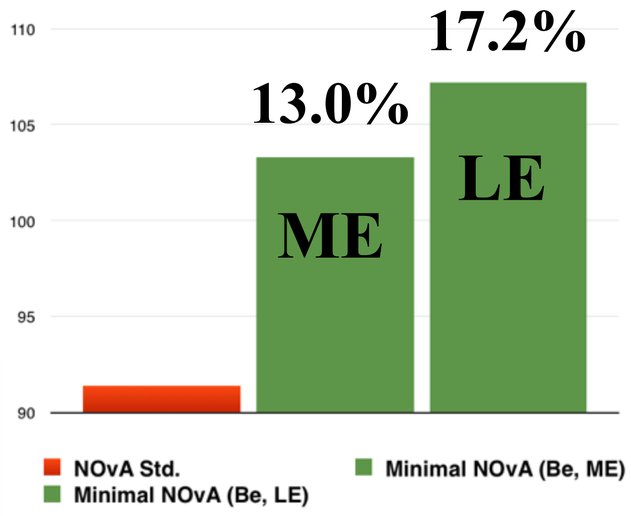
Results: *(FD Events: in 1-3 GeV Energy range)*

% is the gain w.r.t Std. NOvA target

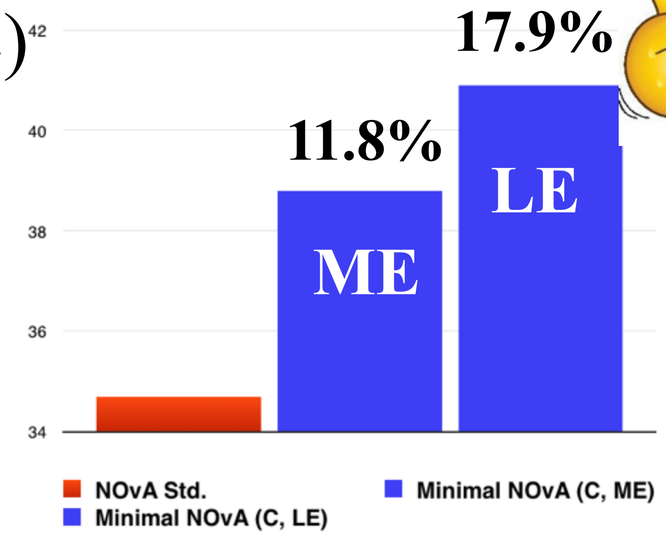
(FHC)



(FHC)



(RHC)



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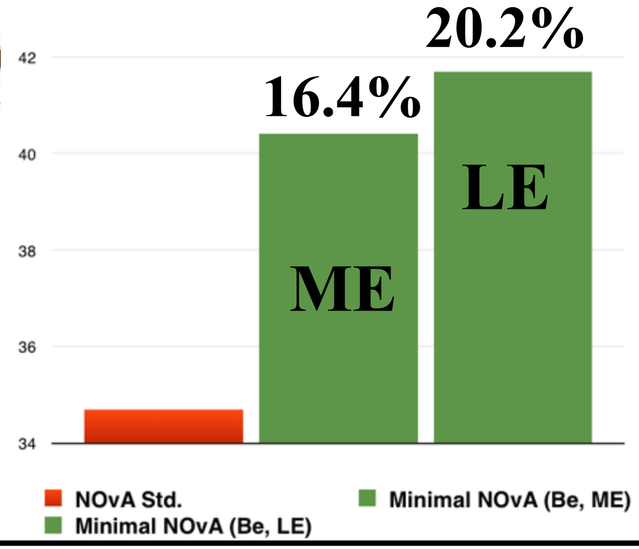


Red: ***Standard NOvA***

Blue: Graphite (C) Fins Minimal NOvA Target

Green: ***Be Fins Minimal NOvA Target***

Horn2 configuration

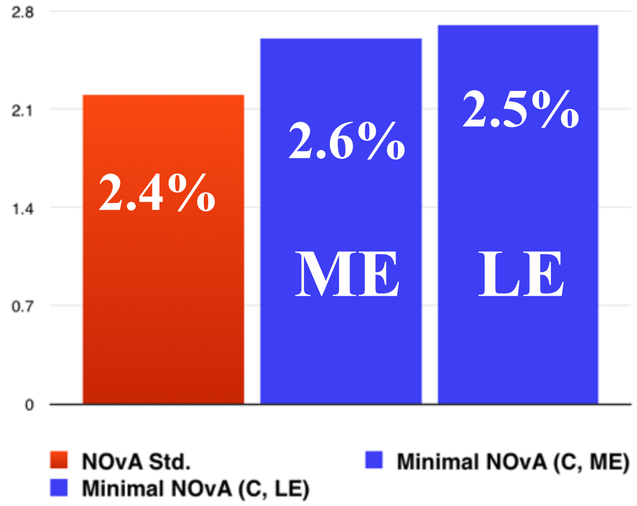
ME: Horn2 @+19.18m

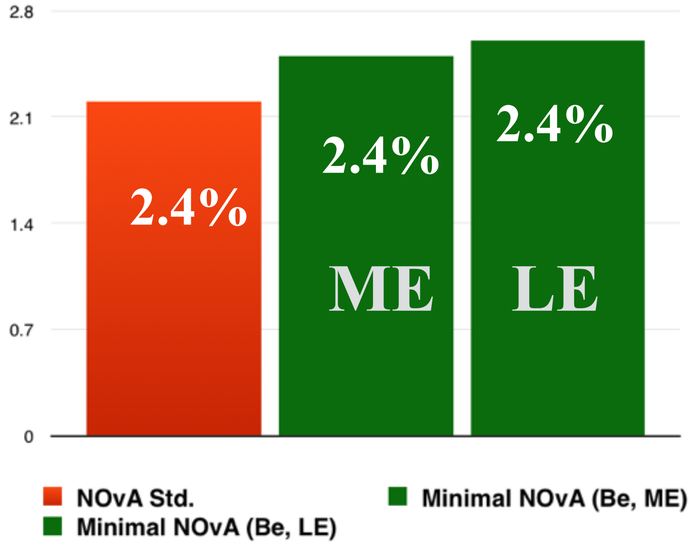
LE : Horn2 @+10m

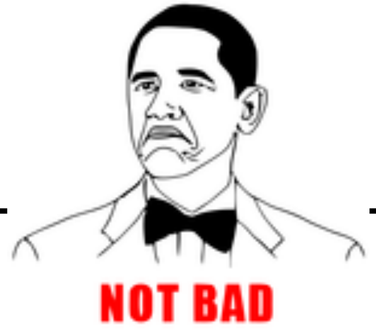
Background to the ν_μ yield

% here is w.r.t ν_μ yield

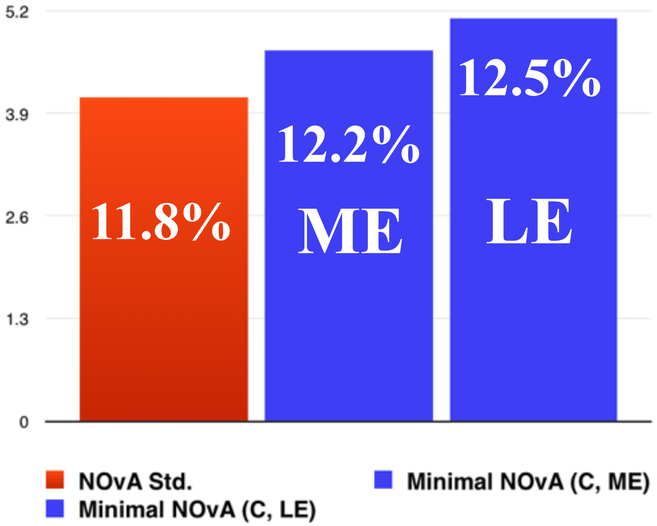
(FHC)

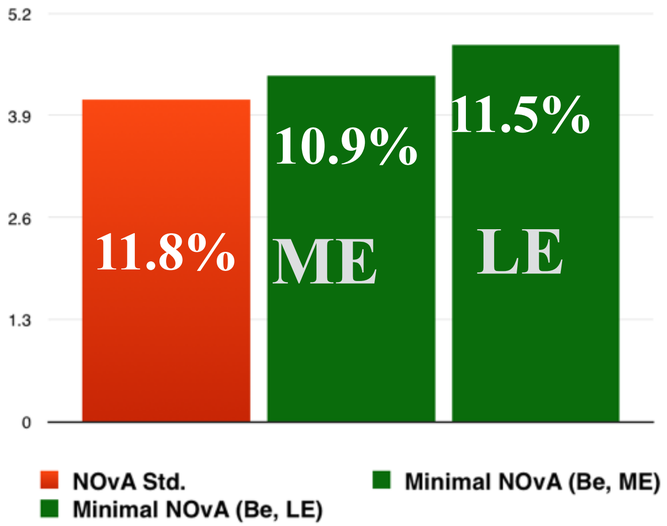






(RHC)





Summary & Conclusions

- We have studied different NuMI target design (which goes inside the Horn1) to optimize the neutrino and anti-neutrino yield at the NOvA ND and FD.
- Minimal NOvA target gives **about 17% (20%) more neutrinos (anti-neutrinos)** as compared to the Standard NOvA target.

This new target design has been discussed with the accelerator division and some engineers (B. Zwaska, K. Yonehara & C. Crowley) who will be doing the thermal analysis of the target heating/cooling & inner conductor of the Horn1 heating/cooling.

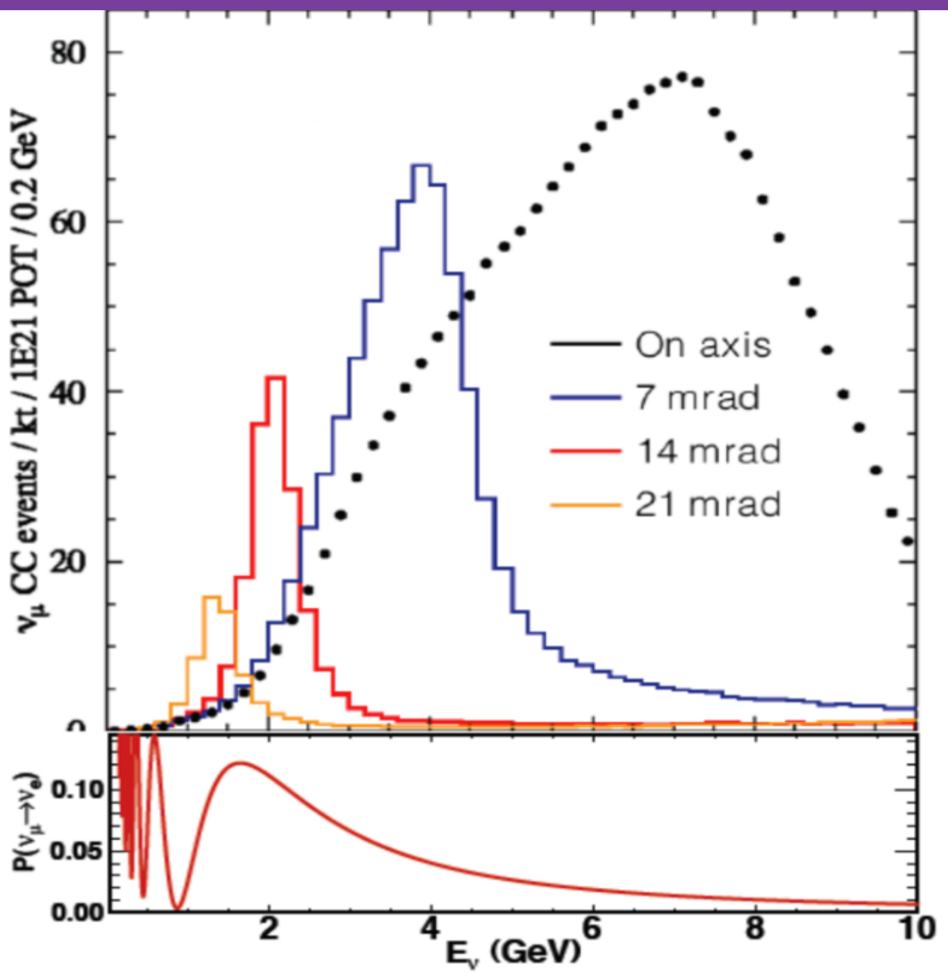
- We expect that this work will have a positive impact on the time required to reach the wanted significance for the oscillation parameters that NOvA is studying.
- Stay tuned!

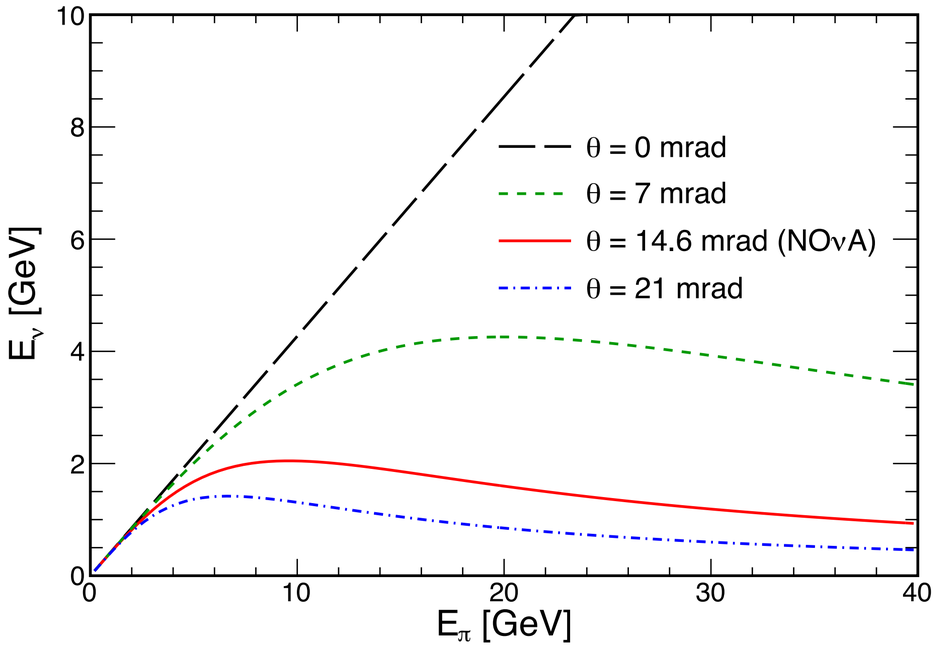
Thank you!

Back-up

Why off-axis ?

- **Off-axis (14.6 mrad) location of the NOvA detectors ensures:**
  A.) Narrow energy peak around 2GeV, where the probability of oscillations is maximum.
  B.) Reduces Neutral Current background (the main background component to ν_e appearance channel) .





- C.) Less variation in neutrino energy w.r.t the parent pion energy (compensating for the decrease in flux).

Choosing the best target position and configuration

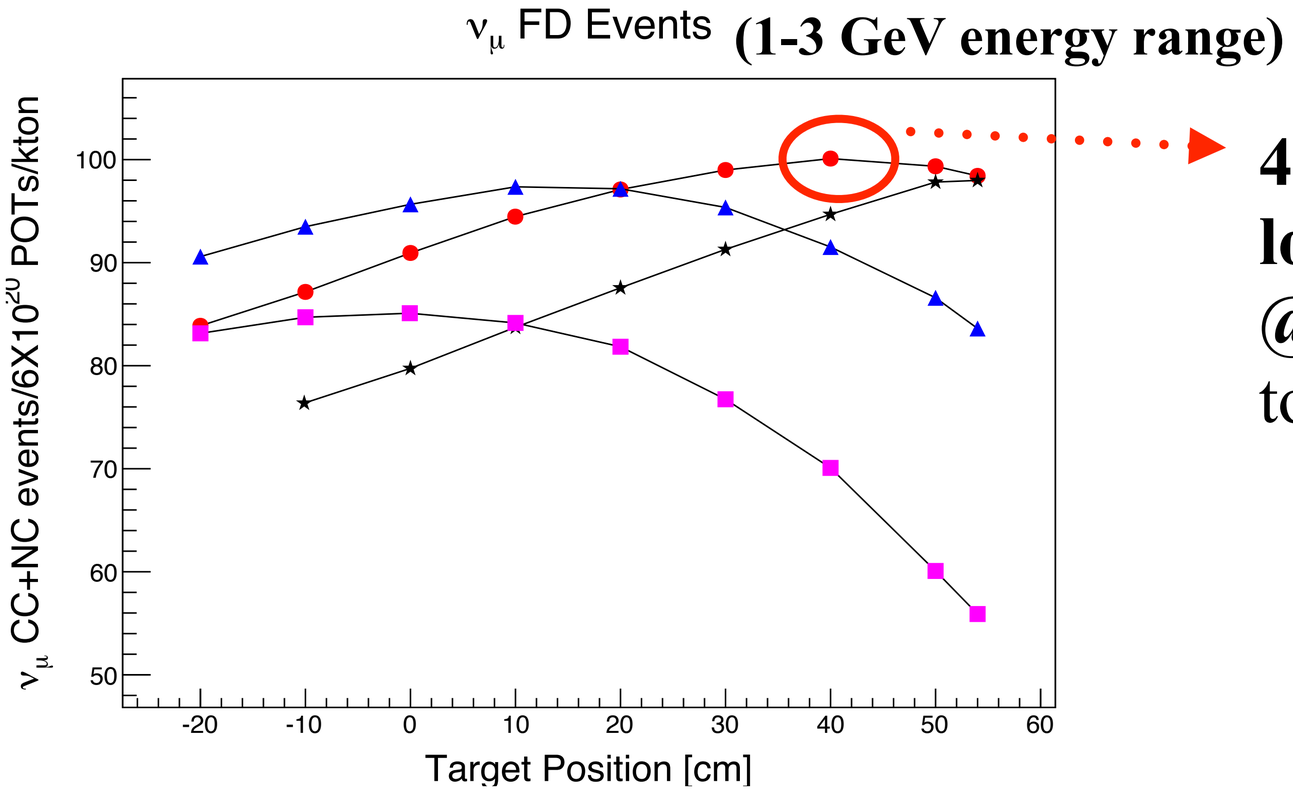
- Simulate Minos short target of different lengths at various target positions.

Magenta: 24 fins
~64cm long

Blue: 36 fins
~93cm long

Red: 48 fins
~122 cm long

Black: 60 fins
~147cm long



48 fins target (~122cm long) configuration **@40cm** position seems to be the best one.

- We checked this further using different targets and they all showed maximum yield with **target positioned @+40cm (inside the Horn1).**

FLUGG software

- Monte Carlo simulation package with
  A.) **Geant4 :** for geometry description.
  B.) **FLUKA interface:** for actual particles physics.

Flugg version: 2009_3

Fluka version: fluka2011.2c.4

Simulated 500k POTs for both FHC & RHC configuration.

Technical challenges of the target design

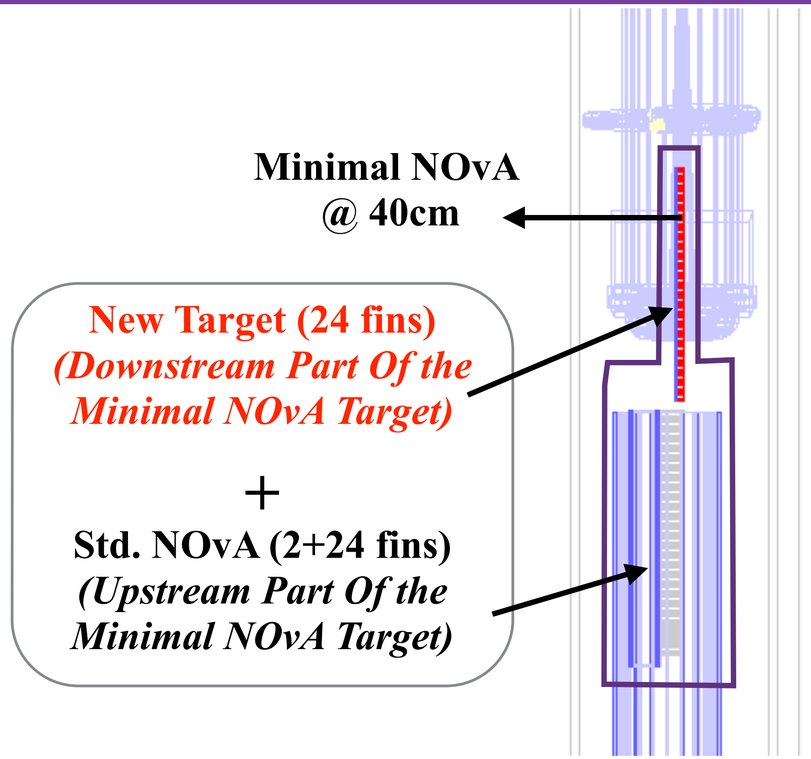
- Minimal NOvA target requires an engineering design .

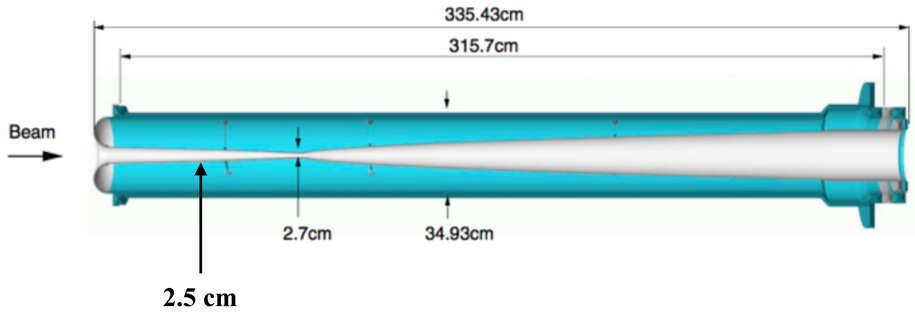
  - *To connect the upstream part of target (Std. NOvA with 24 fins) to the new target (which goes inside the Horn1) would be challenging.*

  - *We had removed Be window and target downstream flange from the standard NOvA target to avoid overlapping MC sections in FLUGG.*

  - *The radius of the surrounding tube of the **new target part** (which goes inside the Horn1) is 2.15 cm and at +40 cm w.r.t Horn1 inner conductor of Horn1 is 2.54 cm. So, ~4mm radial clearance between this **new target** and the Horn1.*

  - *Heating/Cooling of the Horn1 inner conductor should be considered but the downstream part of the target requires less cooling as compared to the upstream part because of lesser interactions in the downstream part of the target.*





Costs:
Thanks to John W.Cooper (NOvA Project Manager) for providing these figures

For a new target:

WBS 2.0.3.2.1 ME Target, Carrier & Baffle (For new target design, should be able to use existing MINOS carriage)

Materials and Services	= $ 455,455
Personnel Costs	= $ 997,578
TOTAL COST	= $1,972,667

This included all the design, construction, and installation of the existing NOvA target built by the NOvA Project

For Horn 2 in a new position:

WBS 2.0.3.3.2.1 Stripline Extension

Materials and Services	= $ 125,935
Personnel Costs	= $ 207,276
SUBTOTAL COST	= $ 333,211

WBS 2.0.3.3.2.2 Shielding Reconfiguration

Materials and Services	= $ 346,661
Personnel Costs	= $ 545,659
SUBTOTAL COST	= $ 892,319
TOTAL COST	= $1,225,530

This included all the design, construction, and installation of a new stripline based on the move of Horn 2 from 10m to 19m in the NOvA Project.