Conceptual Design of the CN2PY secondary beam line & CN2PY related activities at CERN

XVth NuFact International Workshop
IHEP Beijing, 19-24th August 2013

Ph. Velten on behalf of the
LAGUNA-LBNO WP4 at CERN

Topics

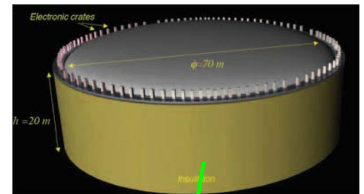
- Presentation of the LAGUNA-LBNO design study
- Overview of the activities on-going at CERN:
  - The HP-PS project
  - The conceptual secondary beam line design
    - Design of Secondary Target
    - Beam Optics Optimization
    - Muon Shielding
  - The facility layout proposition
- Summary and perspectives

Engineering Department

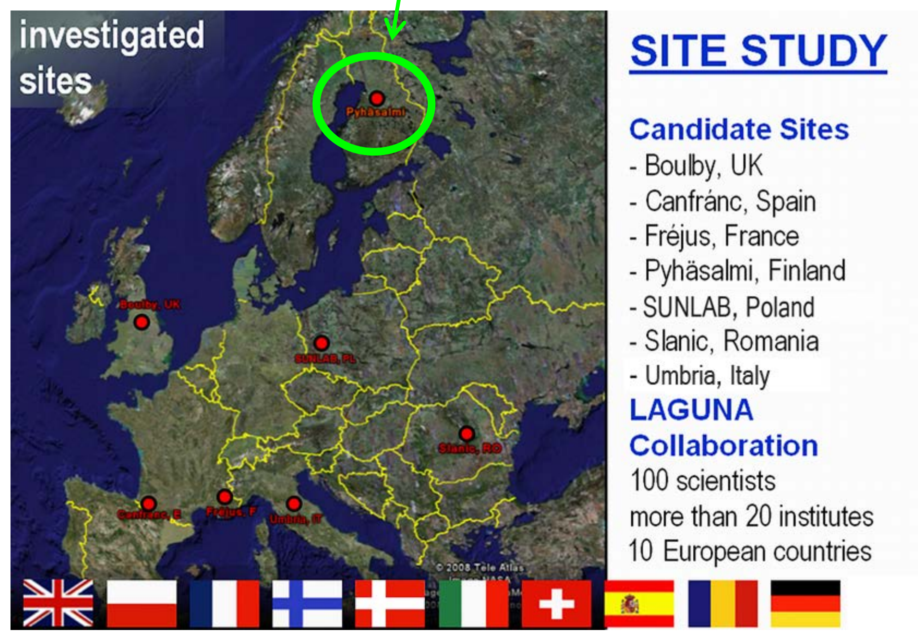
The LAGUNA-LBNO design study

LAGUNA:

- Assessment of the possibility of research infrastructure to host the next generation very large, deep underground neutrino observatory
- **Ended in 2011, selecting the combination of the deep underground mine at <u>Pyhäsalmi</u> and the <u>Liquid Argon Time Projection Chamber</u> technology for the detector as the best candidate**



"GLACIER" design: 20-100kT LAr TPC



The LAGUNA-LBNO design study

LAGUNA:

- Assessment of the possibility of research infrastructure to host the next generation very large, deep underground neutrino observatory
- **Ended in 2011, selecting the combination of the deep underground mine at Pyhäsalmi and the Liquid Argon Time Projection Chamber technology for the detector as the best candidate**

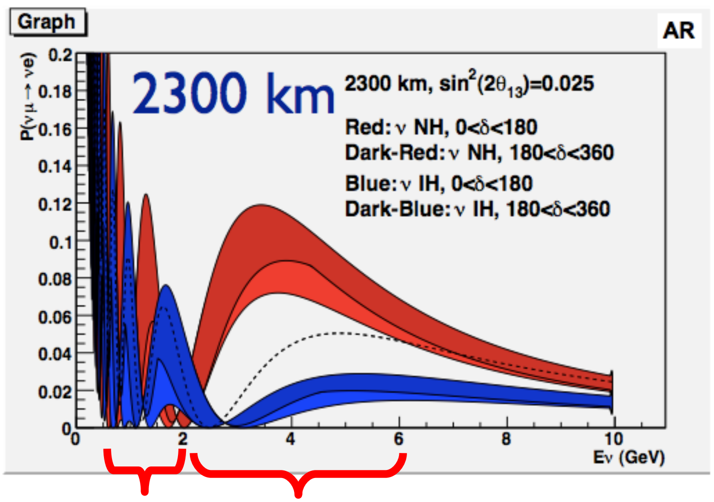
LBNO:

- **GOAL:** extends LAGUNA design study
- End in August 2014
- Development of Underground Construction Plan and Costing
- Detailed engineering of detector construction and operation
- **Prospects for a long baseline neutrino beam from CERN: CN2PY**

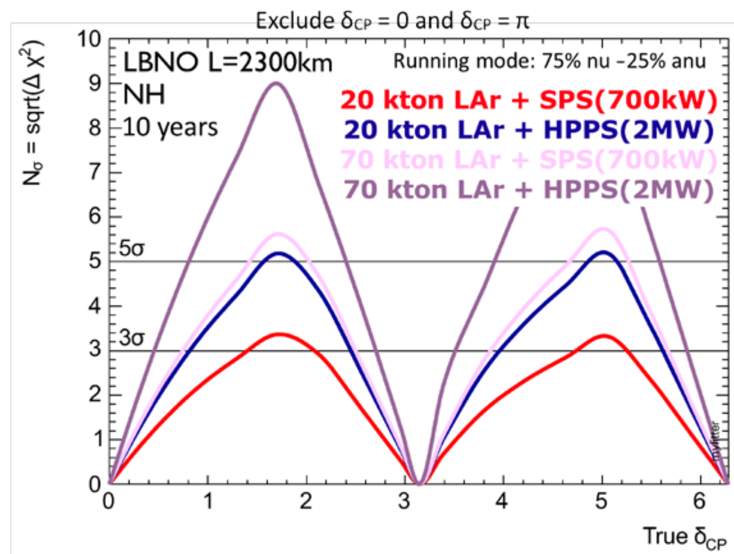
The LAGUNA-LBNO oscillation physics and goals

MEANS:

- Very large LAr far detector (>20kton) at Pyhäsalmi deep underground mine
- Conventional secondary beam line + Near Detector located on CERN site
- Primary beam provided by upgraded SPS p@400GeV/750kW (phase I) and HP-PS p@50GeV/2MW (phase II)
- Opportunity to have a second long beam line coming from Protvino accelerator



2nd osc. max. 1st osc. max.



GOALS:

- determine MH with >5σ CL within two years
- reach >5σ CL on CPV over significant part of the space phase after ~10y of data taking

Activities of the WP4 at CERN

WP4 Structure:

•**Study Group 1:** High Intensity Beams with Present CERN Accelerators
➢Investigate the impact of CERN SPS accelerator upgrade up to ~750 kW

•**Study Group 2:** Proton Beam Transfer
➢Investigate the extraction of SPS beam to CN2PY
➢Find synergies with the CENF project (Short Base Line)

•**Study Group 3: CN2PY Secondary Beam Conceptual Design**

•**Study Group 4: CN2PY Layout Studies**
➢Define the general layout of the facility within CERN territory
➢Interface between the other study groups

•**Study Group 5: HP-PS Design Study**
➢Feasibility study of a 50-75 GeV High Power PS

•**Study Group 6:** Magnetic Configuration of a LAGUNA Detector
➢Study possible technology and configuration, basic performance evaluation

•**Study Group 7:** Near Detector Requirements
➢Understand the detector environment and requirements, development of a conceptual design

PRIMARY BEAM

- **Phase I:** CNGS-type beam from upgraded SPS
  - Use of existing infrastructures
  - **Goal:** 750 kW / 7×10^{13} ppp at 400 GeV (CNGS record: 565 kW / 5.3×10^{13})
  - **Current bottlenecks:** beam losses in PS (radiation issues)
  - Will benefit from LIU-SPS and injector upgrades (RF upgrade and multi-turn extraction in PS)
  - Beam studies resume after LS1

- **Phase II:** High-Power Proton Synchrotron (HP-PS)
  - **Goal:** 2 MW at 50/75 GeV
  - Conceptual design to be delivered in mid-2014

Courtesy of the HP-PS Study Group
(F. Antoniou, A. Alekou *et al.*)

HP-PS design

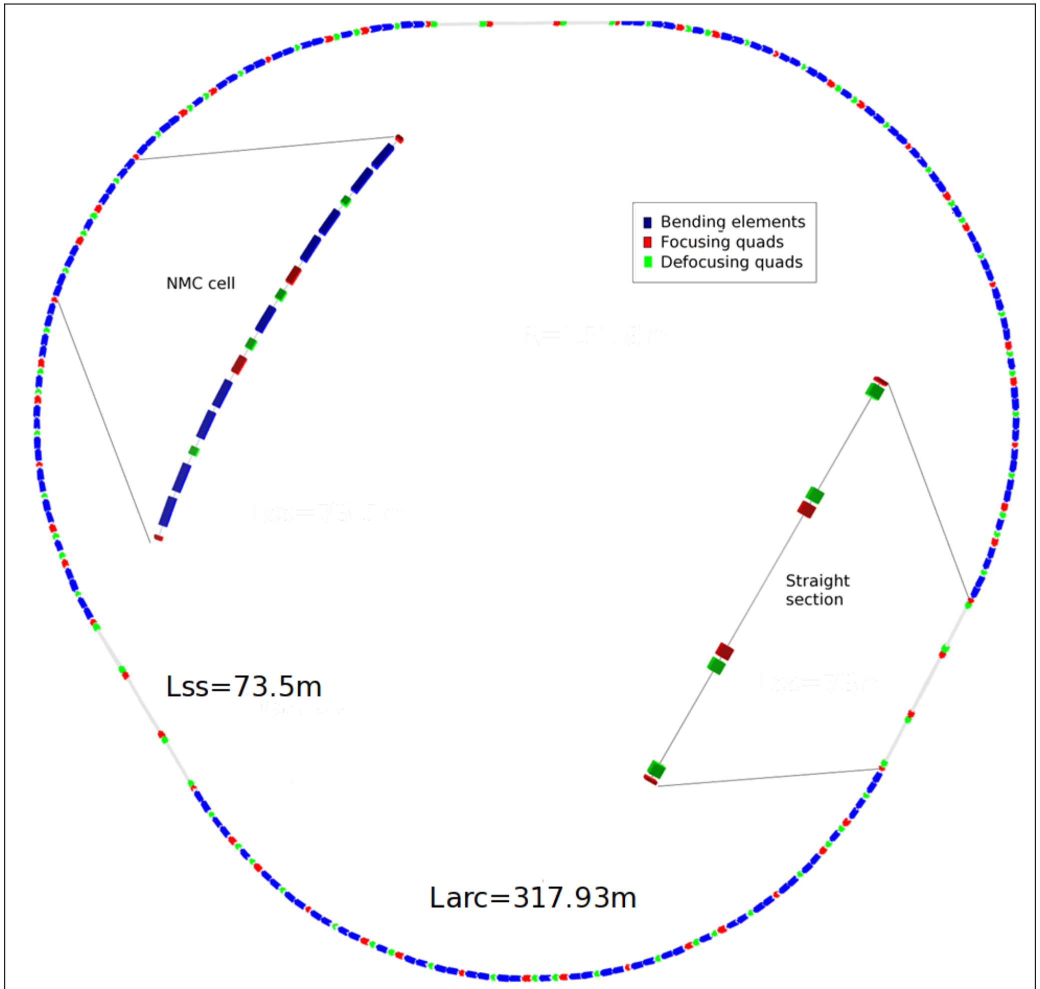
Parameter	50 Gev	75 GeV
Circumference [m]	1174	
Symmetry	3-fold	
Beam Power [MW]	2	
Repetition Rate [Hz]	1	
RF frequency [MHz]	40	
Kinetic Energy @ inj./ext. [GeV]	4/50	4/75
Protons/pulse [10^{14}]	2.5	1.7
Dipole ramp rate [T/S]	4.2	5.9
Bending field @ ext. [T]	2.09	3.13
Max. quadrupole field [T]	1.19	1.53
Dipole gap height [mm]	93	73
Lattice type	Resonant NMC arc , doublet LSS	
Norm. emit. H/V [mm-mrad]	15/12.3	10.6/8.3

- Study of a **High-Power PS** with a **2 MW proton beam** for neutrinos (LAGUNA-LBNO)

- **50 GeV option (Baseline)**
  - Conventional magnet technology (magnet feasibility studies demonstrated for the PS2 design studies)
  - More demanding beam dynamics due to high bunch charge
- **75 GeV option (Alternative)**
  - Demanding magnet technology (Superferric dipoles of 3.13 T field and high repetition. rate)
  - Reduced bunch intensity and more relaxed beam dynamics

Courtesy of the HP-PS Study Group
(F. Antoniou, A. Alekou *et al.*)

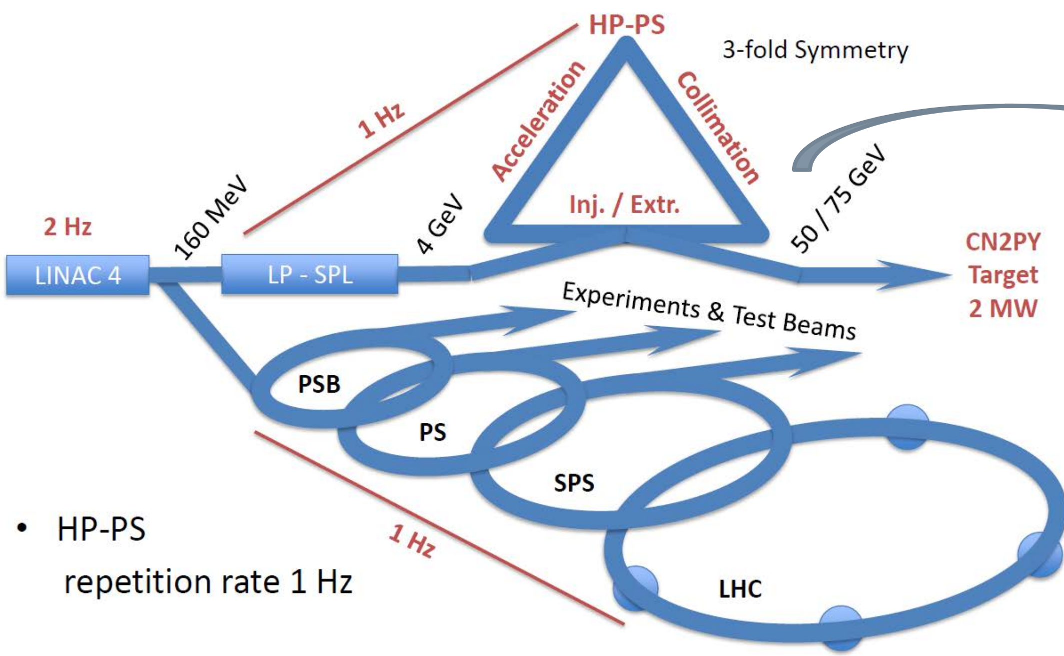
Ring Layout

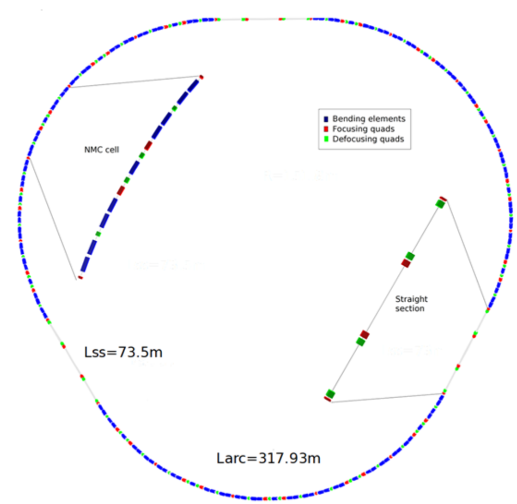


- 3-fold symmetric ring with NMC (Negative Momentum Compaction) arcs and doublet straight sections (for injection/extraction elements, RF system, collimation)

Courtesy of the HP-PS Study Group
(F. Antoniou, A. Alekou *et al.*)

Status of the HPPS design





- HP-PS
  repetition rate 1 Hz

- **The single-particle optics design studies are now completed**
- **Currently under study:**
  - Collimation system optimization
  - RF design
  - Magnet design
  - Collective effects: space charge with realistic
  beam coming after painting, instabilities, impedance budget
  - Beam instrumentation inventory

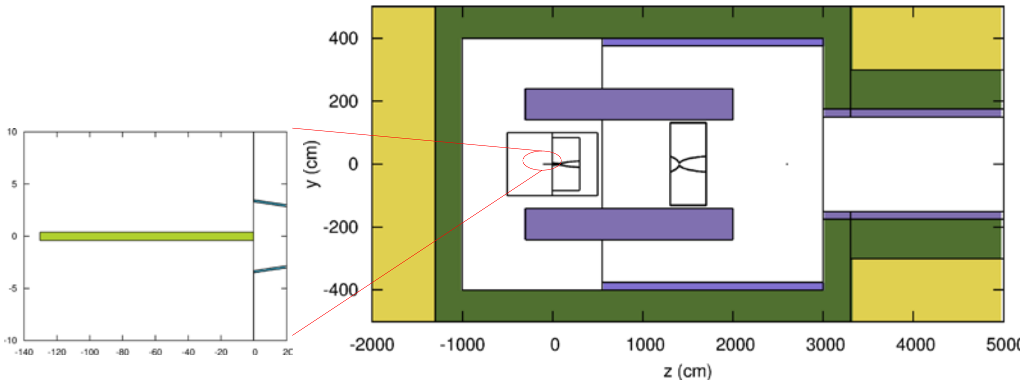
More information:
Y. Papaphilippou *et al.* Design Options of a High-power Proton Synchrotron for LAGUNA-LBNO *Proc. of IPAC2013, Shanghai*, 2013. THPWO081

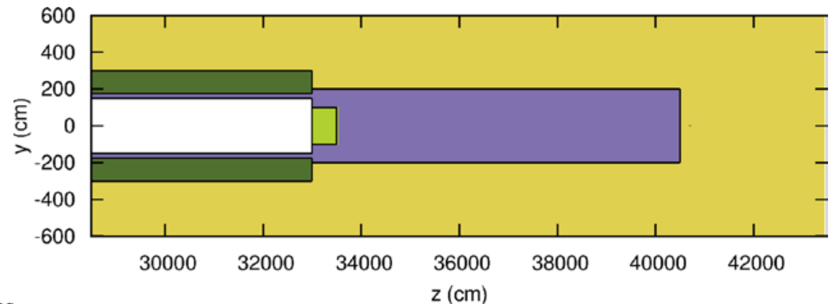
Secondary beam line design

- **Objective:** full description of the beam line facility in FLUKA to provide
  - realistic neutrino fluxes as optimized as possible for LBNO physics goals,
  - detailed energy deposition studies to assess the need for ventilation and cooling in all part of the facility,
  - prompt and residual dose rates to assess the shielding requirement to comply with RP safety rules

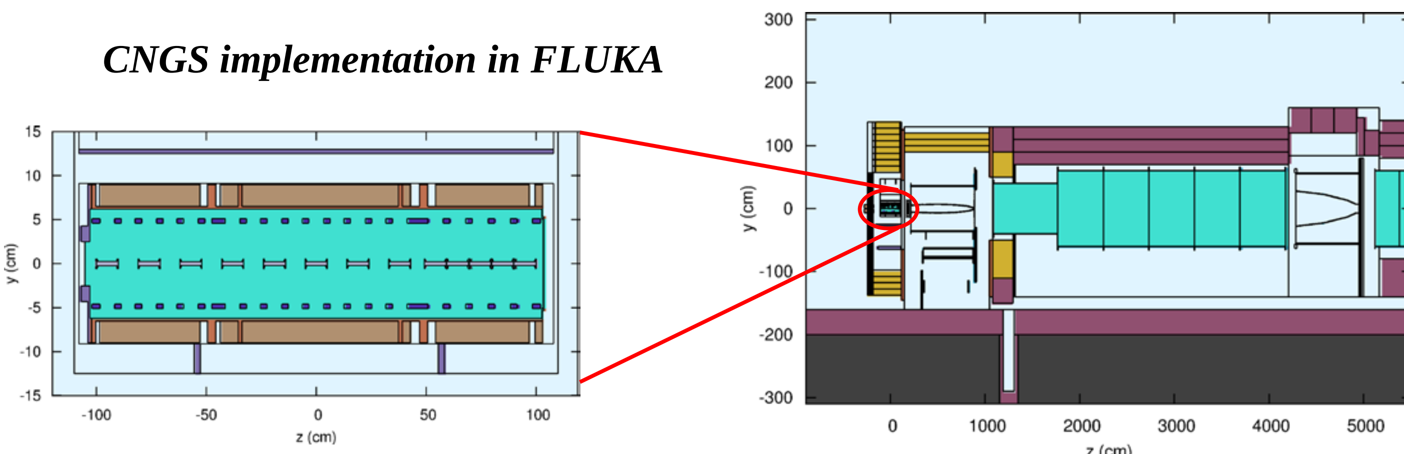
Secondary beam line design

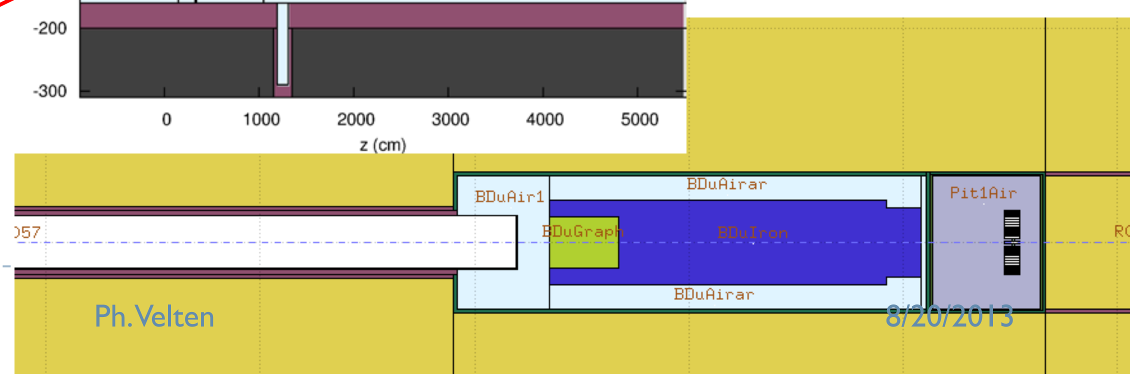
Preliminary CN2PY implementation in FLUKA





CNGS implementation in FLUKA





Current Status of the conceptual design

- Simple but complete description of the secondary line in FLUKA
- Target design: preliminary geometry and energy deposition study
- Achieved 1st iteration of beam optics optimization:
  - beam line parameters tuned to enhance neutrino flux at FD around both first oscillation maxima and phase I primary operation: p@400 GeV / 750 kW
  - Beam optics based on modified "NuMI style" 2-horns system
- Assessment of the neutrino beam's sensitivity to the Decay Pipe configuration
- Shielding requirements after the Beam Dump to protect ND from HE muons
- Availability of neutrino fluxes of all 4 species enables more realistic near and far detector simulations

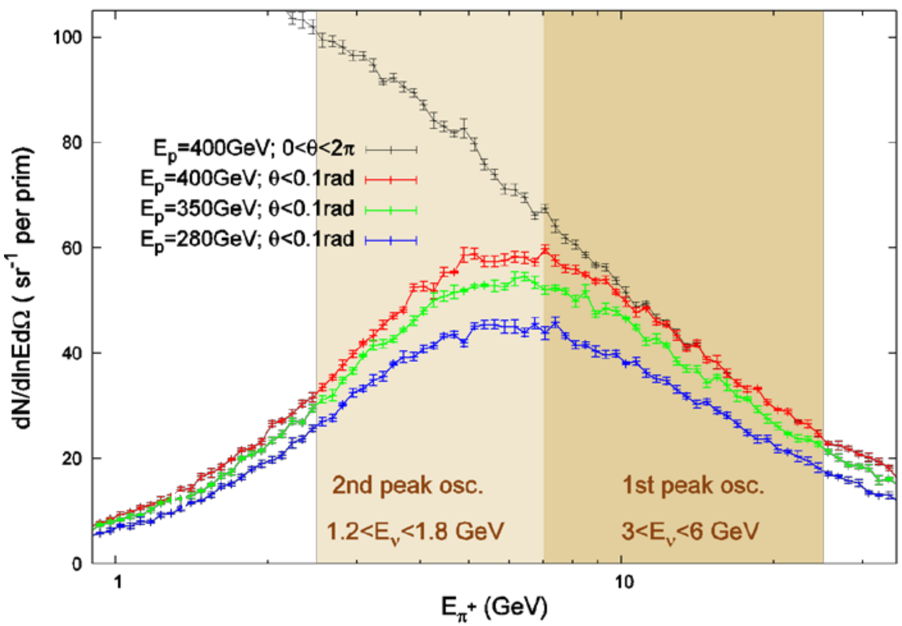
Main parameters of the beam line

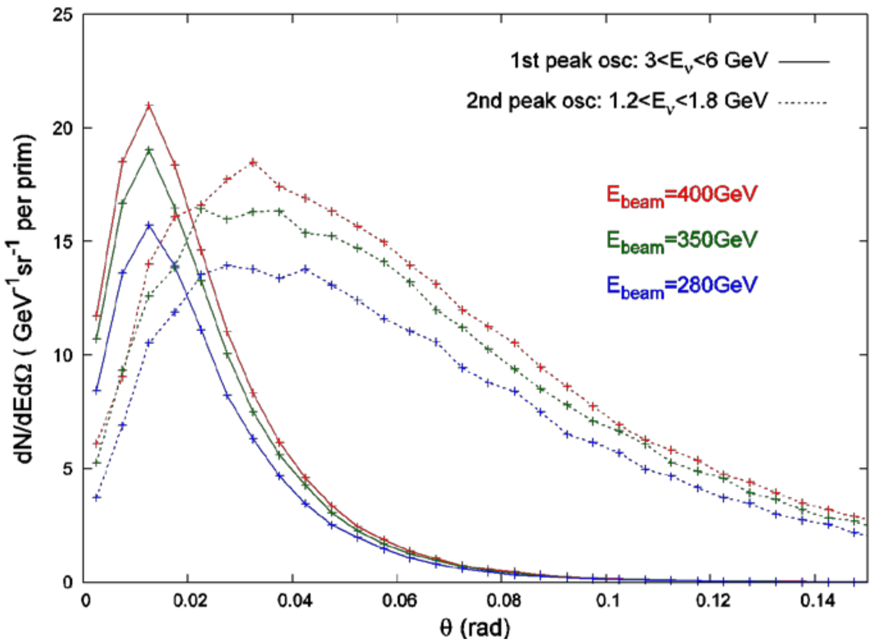
Items	Symbol	Value	unit
Target length	l_{tgt}	1.3	[m]
Target radius	r_{tgt}	4	[mm]
Target material		graphite	
Material density	ρ_{tgt}	1.85	[g/cm^3]
Horn and Reflector inner shapes		NuMI (Longhin)	
Horn length	l_H	3	[m]
Horn current	I_H	220	[kA]
Reflector length	l_R	3	[m]
Reflector current	l_R	225	[kA]
Distance between target horn	Δ_{tgt}	0	[cm]
Distance horn and reflector	Δ_{HR}	8	[m]
Angular acceptance $\sim$ 11 GeV pions (1st osc. max. ν_μ)		≤ 60	[mrad]
Angular acceptance $\sim$ 4 GeV pions (2nd osc. max. ν_μ)		≤ 100	[mrad]
Distance target and decay tunnel		20	[m]
Decay tunnel length	l_{dcyp}	300	[m]
Decay tunnel diameter	d_{dcyp}	3	[m]
Hadron stopper + Passive shielding length	l_{dump}	100	[m]
Hadron stopper + Passive shielding diameter	d_{dump}	3.8	[m]
Muons flux requirement at Near detector (TOSCA TDR)		2.5	[$/m^2/10^{13}$p]
Distance between target and Near Detector	Δ_{ND}	800	[m]
Distance between end of decay tunnel and Near Detector		480	[m]

TARGET DESIGN – Particle Yield

- Secondary yield scales with primary beam energy
  - highest available primary energy (at given intensity) is preferred to maximize secondary yield

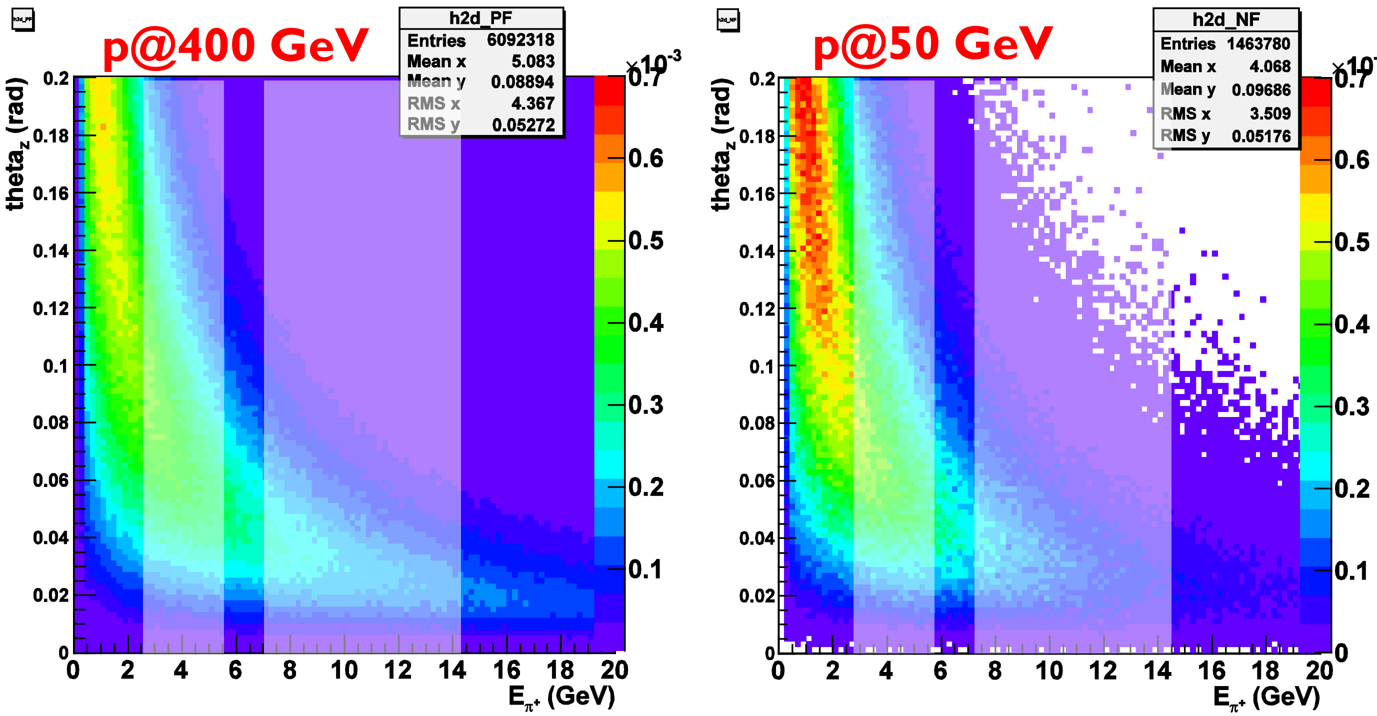
- "Target located outside of horn" design limits the angular acceptance of the focusing system to ~0.1rad
  - Preferred solution for the point of view of engineering
  - ~40% loss of secondaries generating 2nd max. neutrinos
  - Specific "target inside horn" scenario will also be studied





TARGET DESIGN – Secondary kinematics

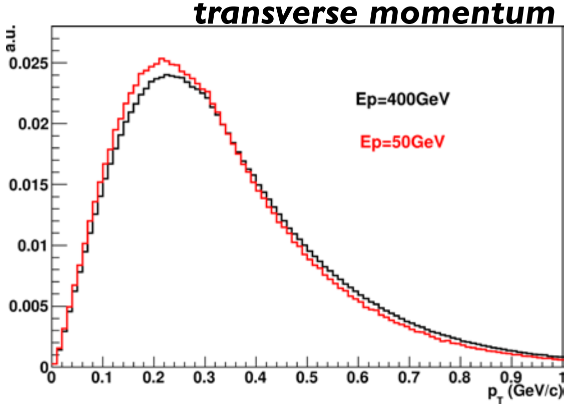
- **Phase I Versus Phase II**
  - Normalized energy and angular distributions



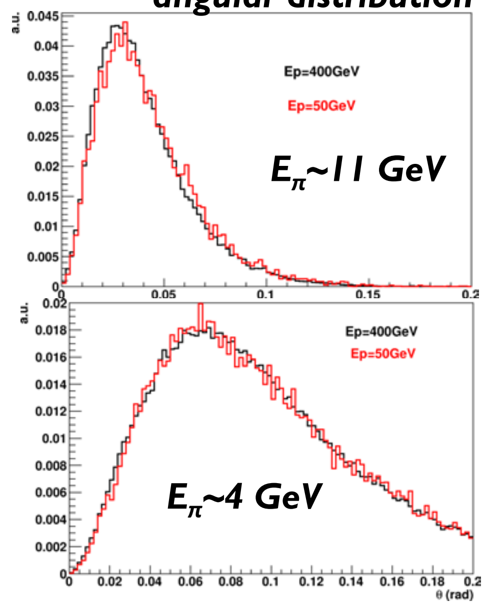
TARGET DESIGN – Secondary kinematics

- **Phase I Versus Phase II**

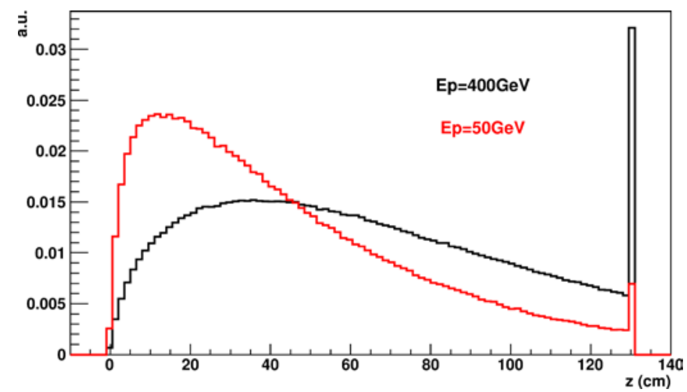
transverse momentum



angular distribution



longitudinal position when exiting the target



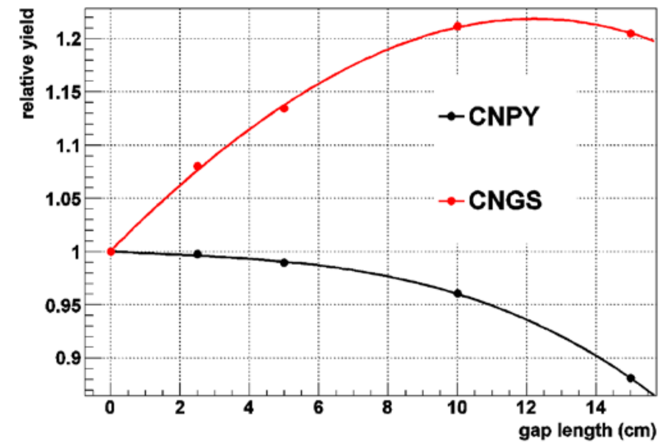
(normalized distributions)

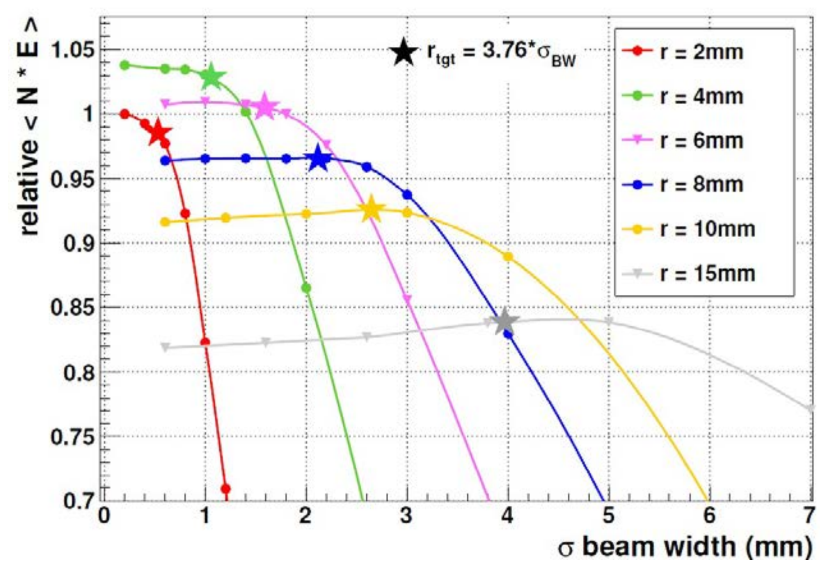
- Significant differences in longitudinal position of secondaries
- Will have impact on the focalization located downstream
- Final optimization of the beam optics will include that effect

TARGET DESIGN – Geometry

- Preliminary design:
  - Be or C solid target
  - ~1.3 meter long
  - No segmentation
  - 4-6 mm radius (1σ=1-1.6 mm)
- Expected radiation damage:
  - phase I: 750kW / 1.5e20 pot/y
    - **0.2-0.5 DPA/y**
  - phase II: 2MW / 2.5e21 pot/y
    - **~5 DPA/y**
- More refined optimization

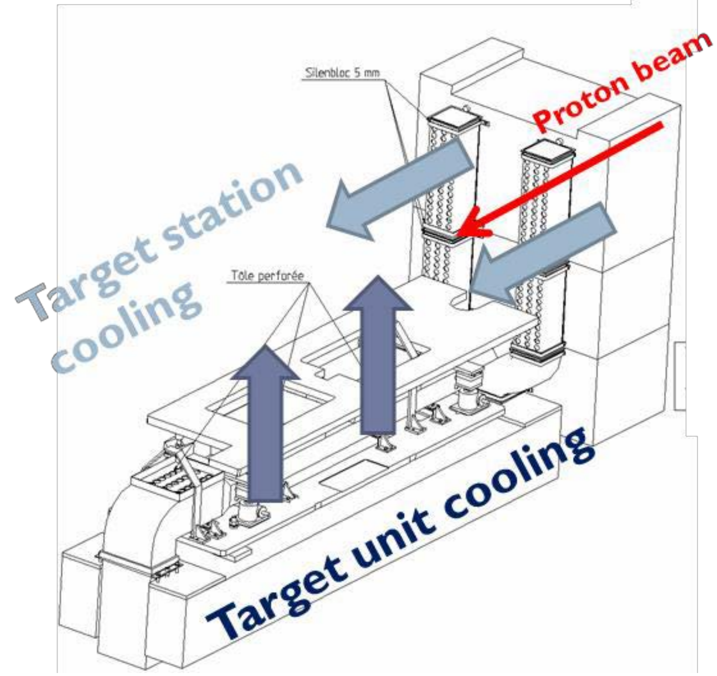
during engineering-driven design studies

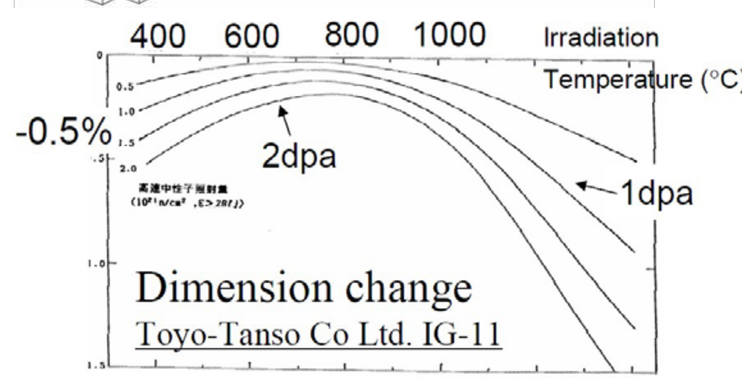




TARGET DESIGN – Engineering considerations

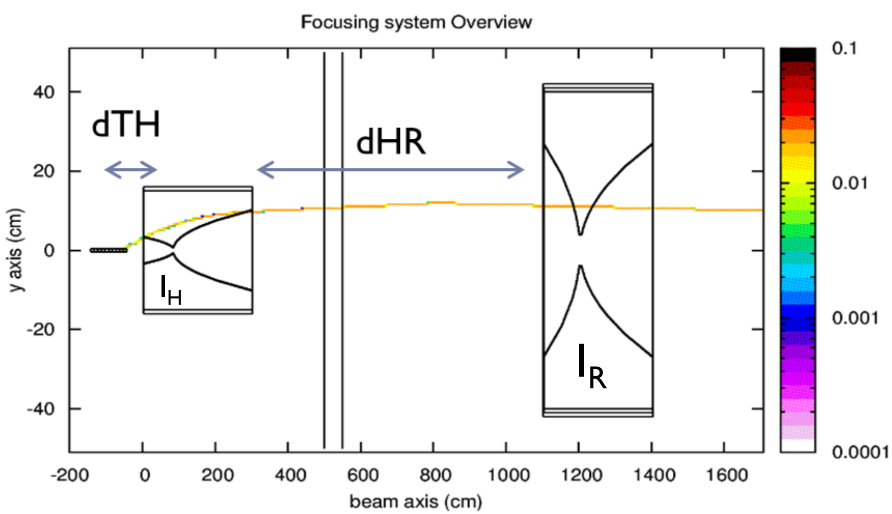
- **Target outside horn:**
  - CNGS-like configuration
  - Radiation-cooled target
  - Ok for 750 kW – more complex for 2MW operation
- **Target inside horn:**
  - Forced-convection He cooling
  - Ok for 750 kW – extendable to 2 MW without major problems
- *High temperature graphite*
  - 600-1000 °C
  - Annealing and reduction of imperfection

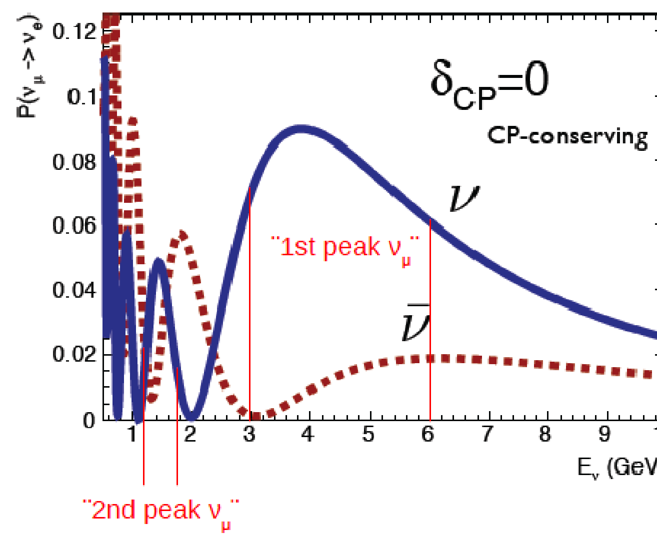




BEAM OPTICS - Current Status of Optimization

- Optimized relative positions and circulating currents of NuMI's style horns proposed in previous studies
- Guideline: Maximization of the ν_μ flux at Far Detector around the 2 first maxima

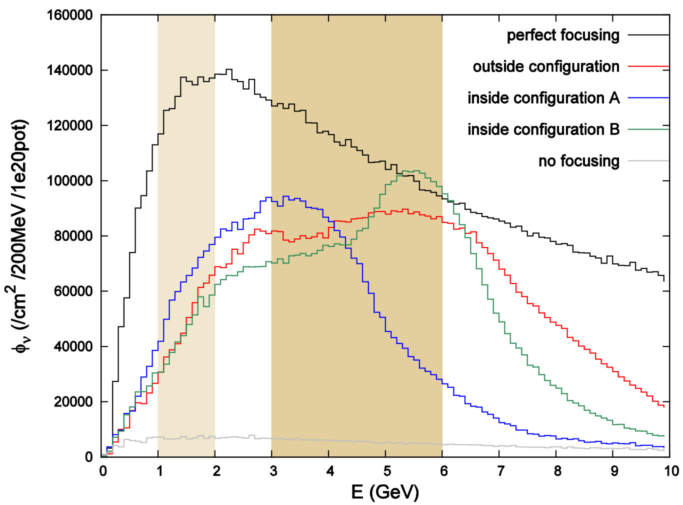




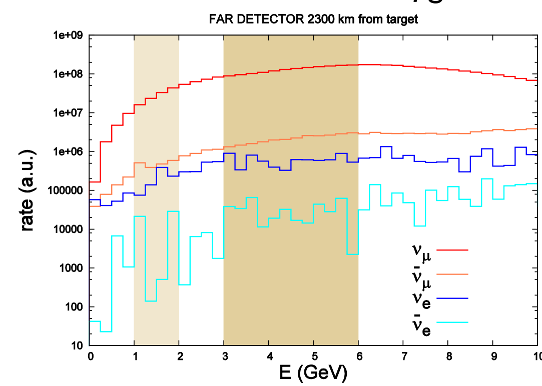
Engineering Department

BEAM OPTICS - Neutrino flux at FD

- Three proposed "optimized" configurations
  - Phase I (400GeV) only
  - "target inside horn scenario" not favored with current horn shapes
  - "Perfect focusing" suggests a possible significant improvement at low energy



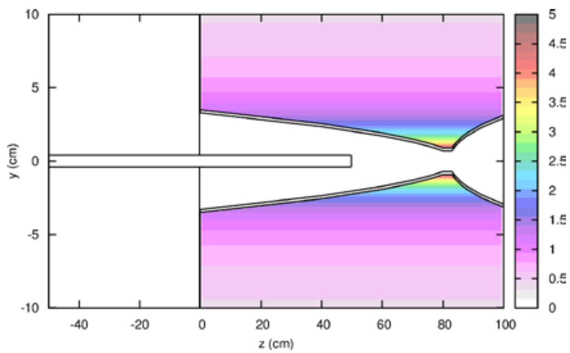
FD neutrino rates
"outside configuration"



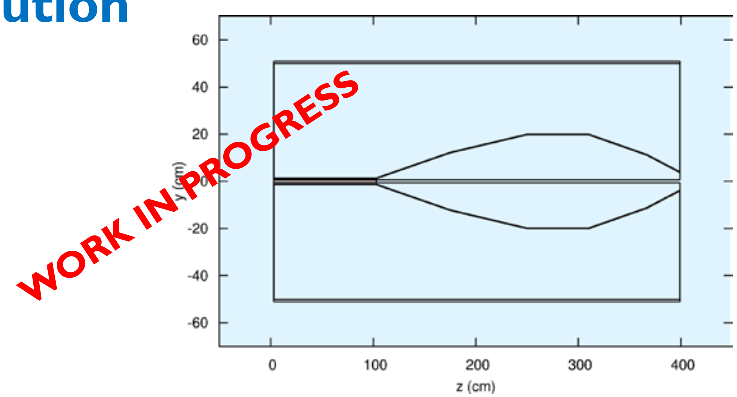
configuration	z_{tgt} (cm)	I_H (kA)	Δ_{HR} (m)	I_R (kA)	Φ_{ν}^{1st}	Φ_{ν}^{2nd}
"target outside horn"	0	220	8	225	11.8 (100%)	1.65 (100%)
"target inside horn" A	+50	175	6	175	7.2 (61%)	1.97 (119%)
"target inside horn" B	+50	175	8	300	10.9 (92%)	1.52 (92%)

BEAM OPTICS – Angular Acceptance

- Acceptance currently limited by the double elliptical horn shapes

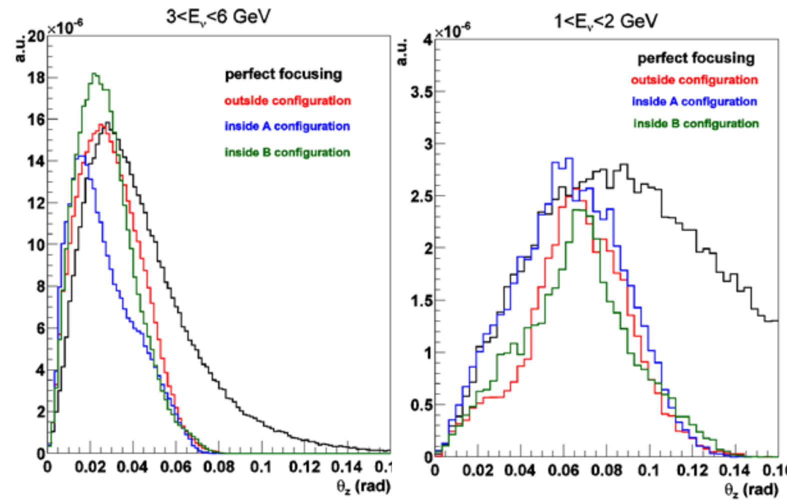


- **Fully enclosing the target in a "collector" horn is the only solution**



Momentum angle of pions before focalization which generated neutrinos at the FD

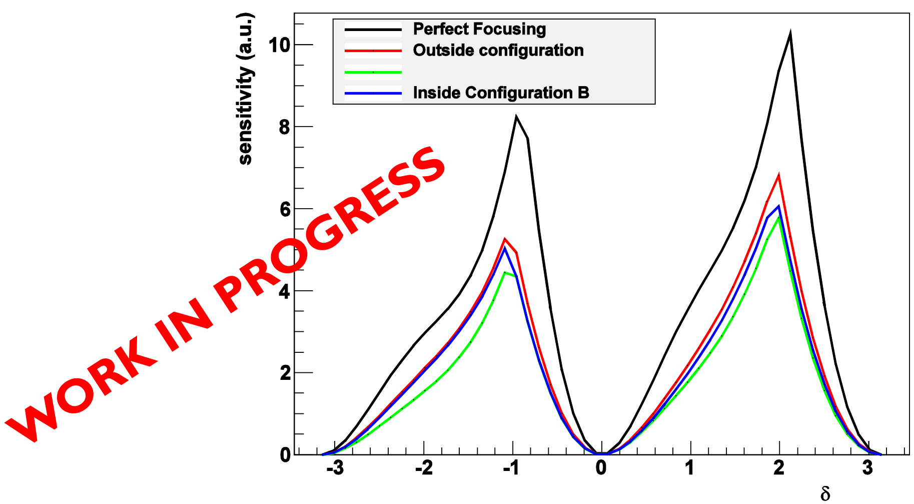
1[st] max   2[nd] max



BEAM OPTICS - Next step of optimization

- New methodology to scan a larger fraction of the beam optics parameters
  - Investigate new horn shapes
  - Assess the need to have dedicated set of parameters for phase 1 and phase 2

- Use CPV sensitivity to estimate a realistic efficiency of each focusing configuration
  - Assess the importance of the 2nd maxima versus the 1st one.

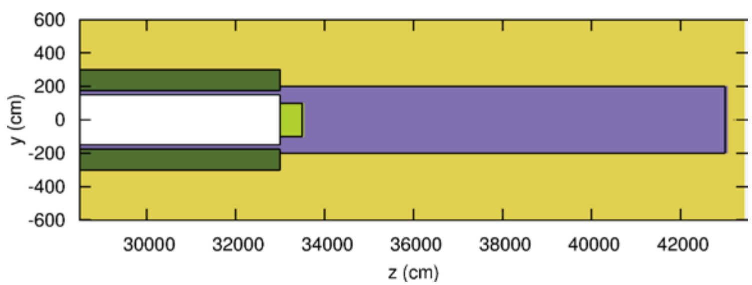


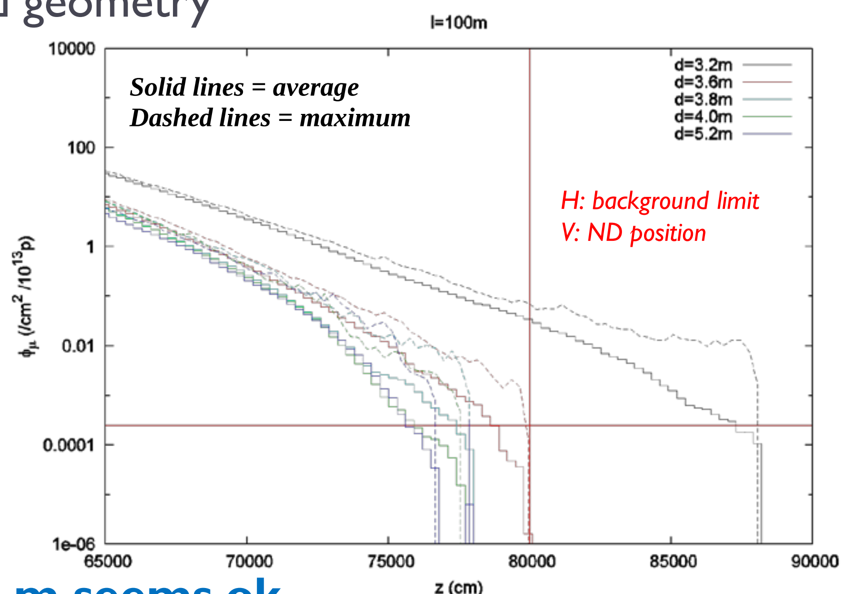
CPV sensitivity generated by "LBNO tuned" GLoBeS (thanks to S. Di Luise, ETH Zurich and V. Galymov, CEA Saclay):

CN2PY + 20kt LAr FD
7.5y NuMu mode + 2.5y ANuMu mode

MUON SHIELD

- Muons reaching the ND causes pile-up for event reconstruction
  - Guidelines from TOSCA TDR: **$< 2.5\ \mu/m^2/10^{13}p$**
  - ND located 800 m after the target
  - MC study to optimize the passive shield geometry





- **Iron cylinder of l=100 m and d=3.8 m seems ok**
  - Similar to WANF shielding for SPS p@400 GeV
  - “Purely active shielding has been investigated as an alternative solution

Layout of the future facility

- Main challenges:

Hard slope to Finland

2 stages for primary beam operation:

-The facility layout is driven by the 400 GeV beam

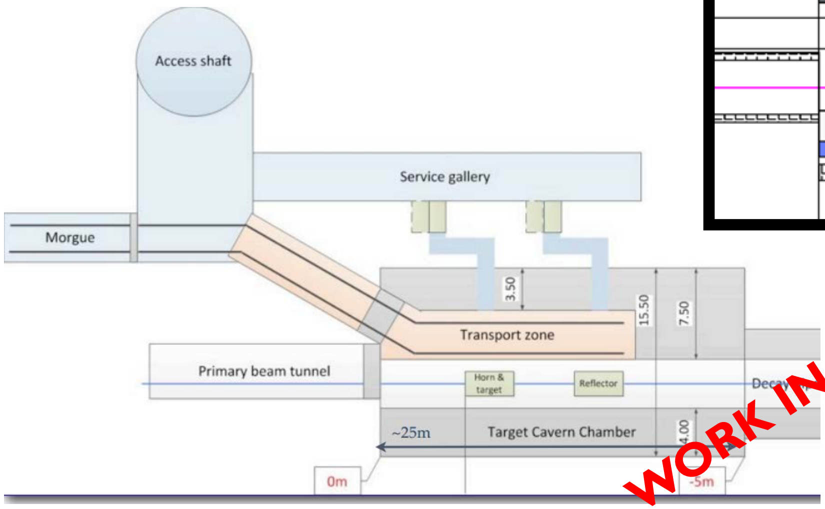
- The target cavern and decay pipe layout (shielding) is driven by the 50(70) GeV beam and the 2MW of power

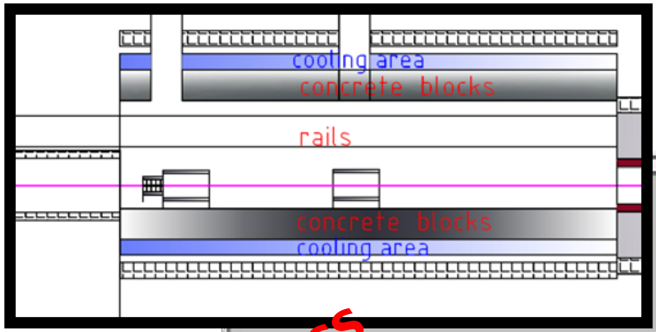
Location on CERN site and plugging scenario to SPS

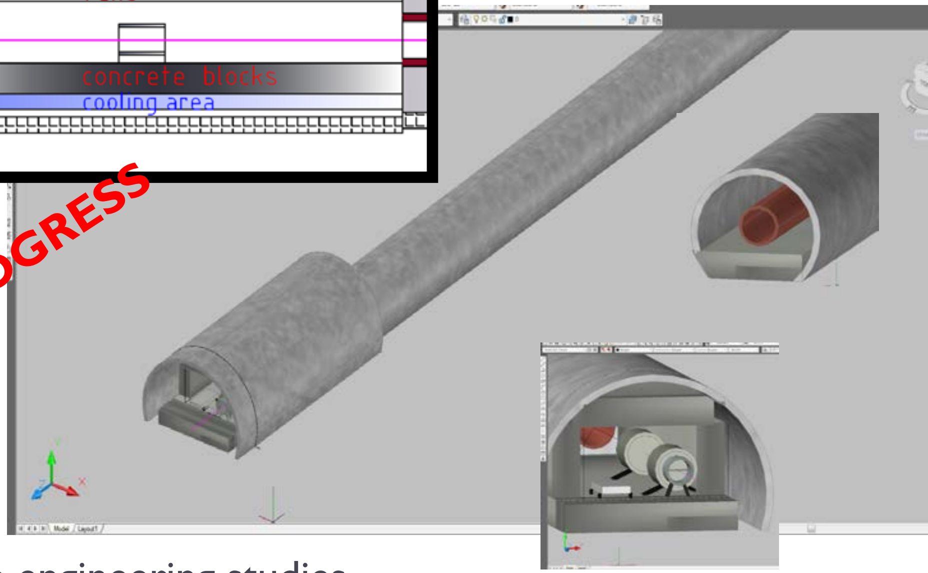
- Objective of the studies:
  - Attempt to foresee and solve most of the issues
  - Optimize safety, long-term maintenance and cost
  - Coordinate civil engineering, accelerator groups, physics requirement

Layout of the future facility

- Implementation of the 1st layout proposition in FLUKA







WORK IN PROGRESS

  - Centralization of the physics studies and the engineering studies
  - Prompt & residual dose calculations in all parts of the facility
- Short-term results: First assessment of the shielding requirements and activation levels

Summary and future activities

- Main parameters of the secondary beam line have been defined
  - Used currently by the LAGUNA-LBNO collaboration for both detector simulations and facility layout study at CERN
- 2nd iteration of neutrino beam optimization is currently under way
  - New procedure based on CPV sensitivity plot
  - Investigate "large acceptance" horn for low-energy secondary focalization
  - Precise assessment of the difference between phase I & phase II on the beam line design
- Perform detailed energy deposition studies in a realistic layout description of the facility
  - First assessment of shielding requirement for RP
  - Initiate "engineering driven" MC studies.

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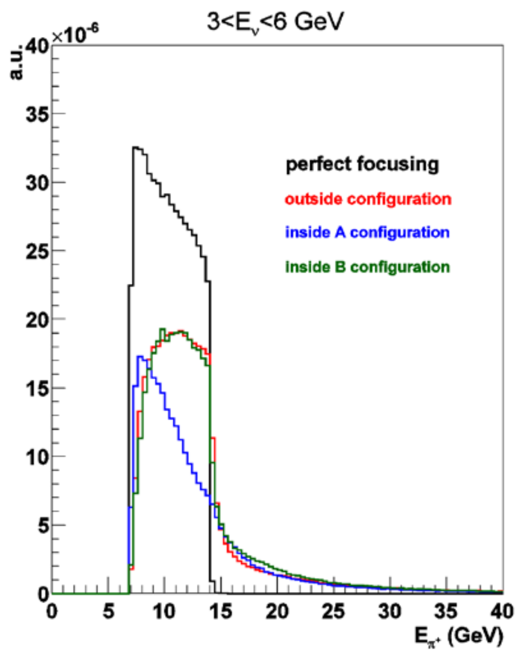
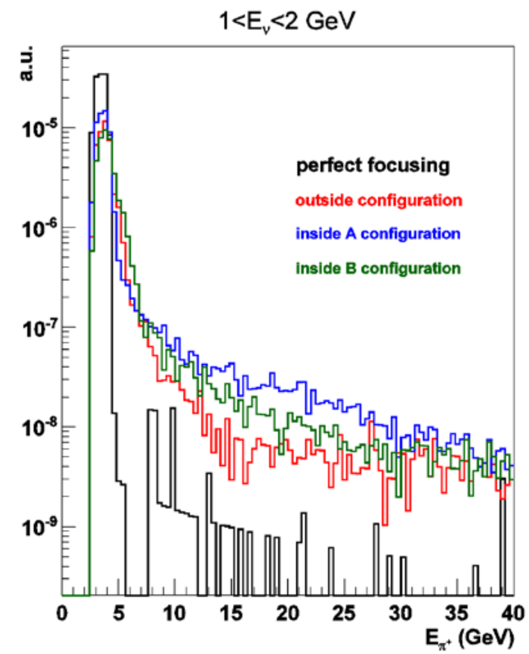
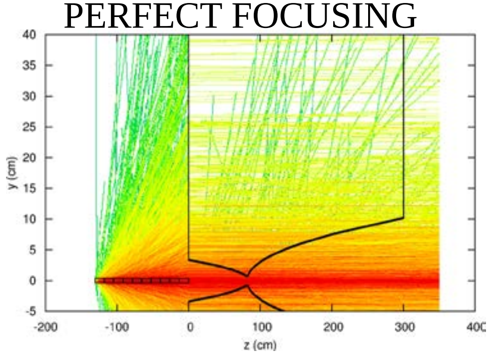
BACKUP SLIDES

Neutrino Parents – Energy Distributions

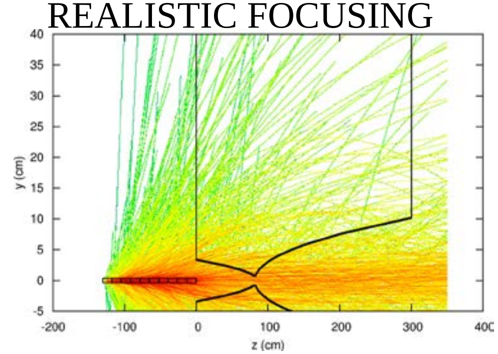




PERFECT FOCUSING

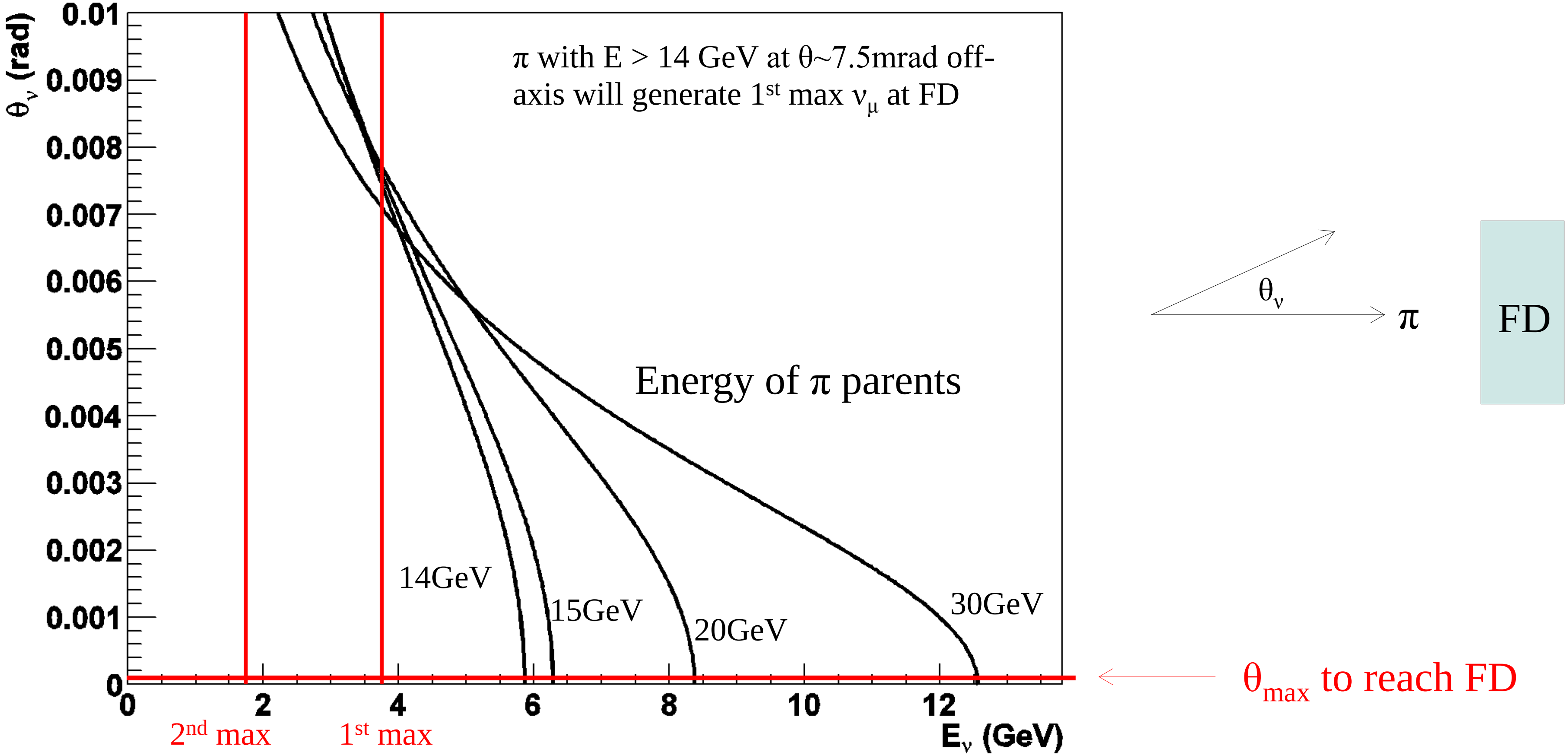


REALISTIC FOCUSING

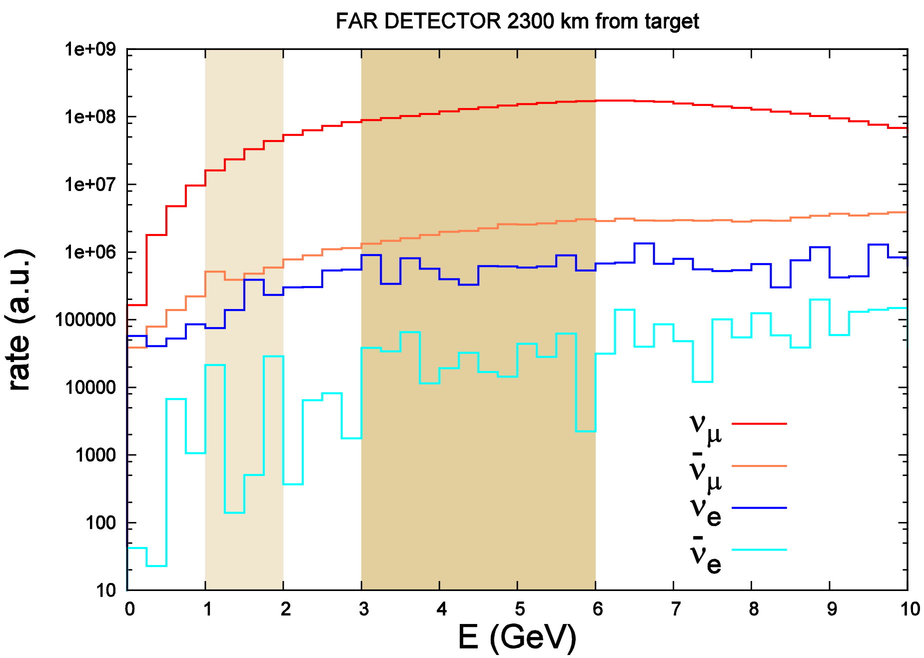


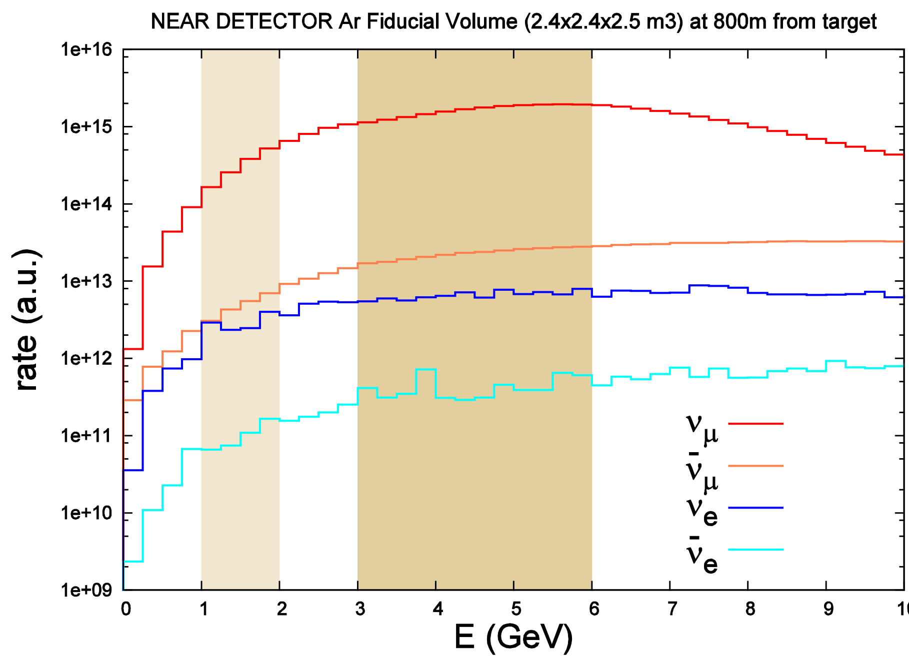
- Perfect focusing ≠ Ideal focusing for $E_\pi > 14$ GeV
- Realistic focusing receive contributions from $E_\pi > 14$ GeV

Neutrino Parents – Decay Kinematics



Count rates at Detectors

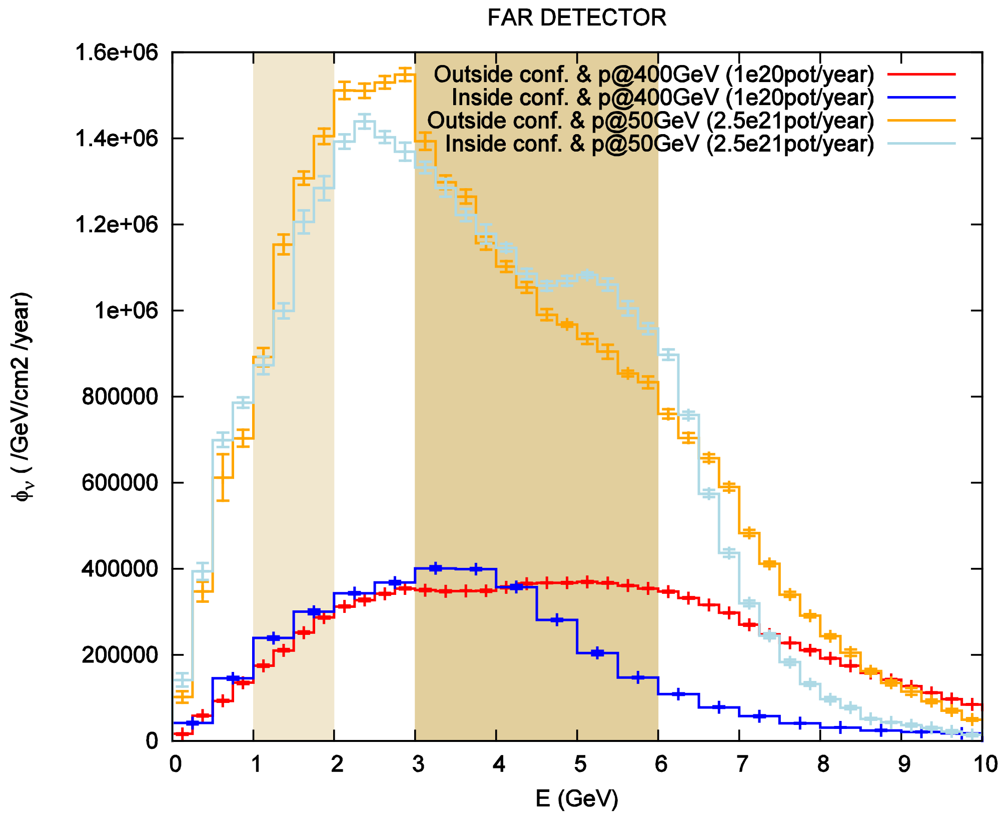




BEAM OPTICS - Neutrino flux at FD

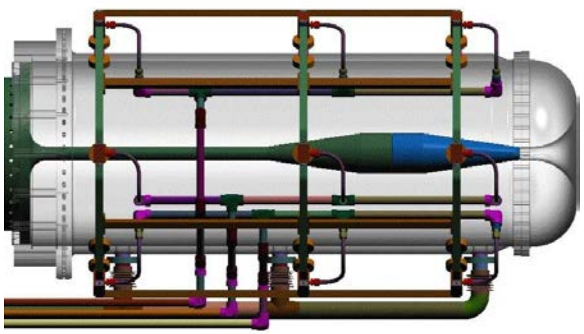
Phase I Versus Phase II

- FD neutrino flux using the phase I optimized beam line

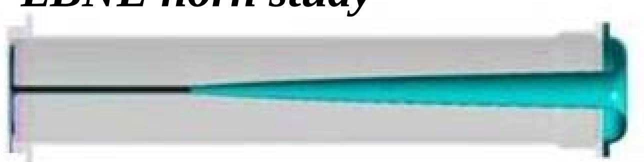


- Existing large acceptance horns

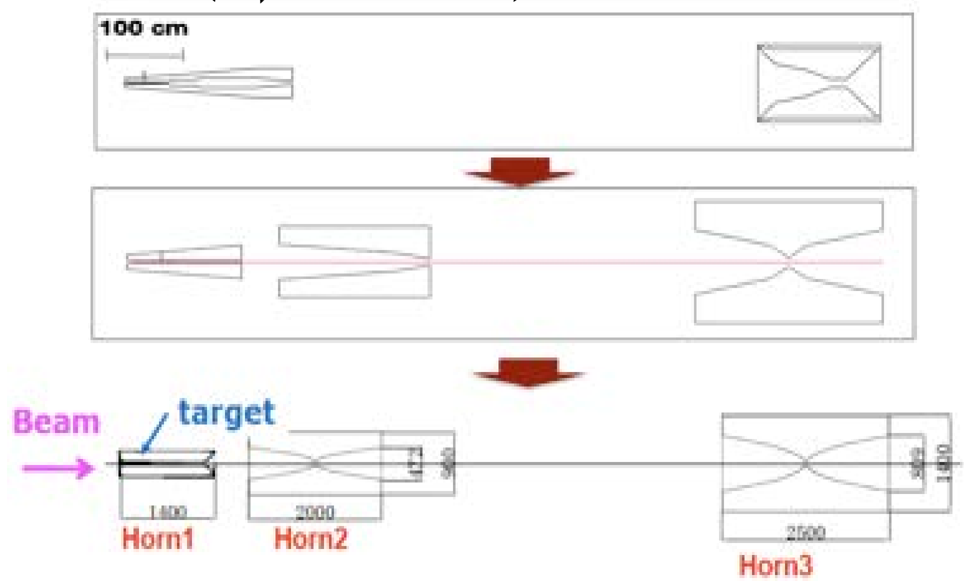
MiniBoone ***(<E_ν>=1 GeV)***



LBNE horn study

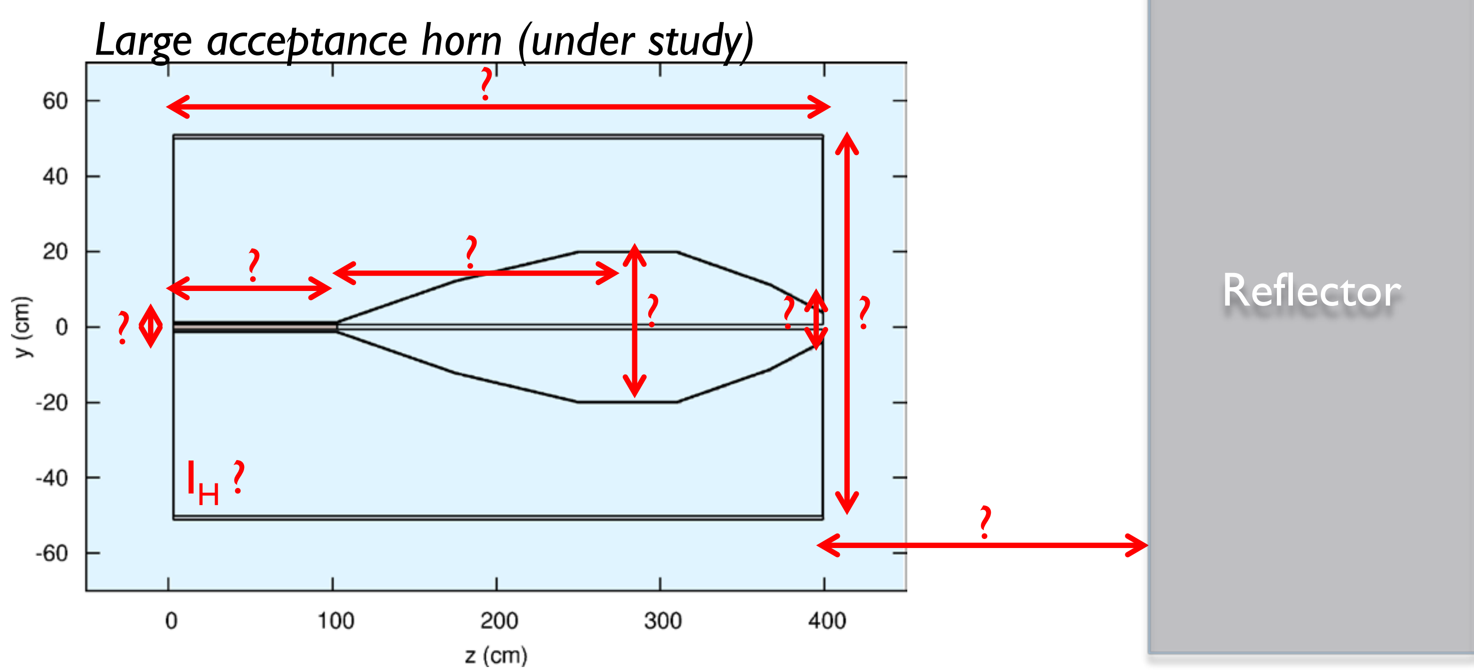


T2K ***(<E_ν>=1.5 GeV on-axis)***



BEAM OPTICS OPTIMIZATION - Investigating new horn shapes

- Huge number of degrees of freedom
- New methodology under investigation to scan efficiently all the interesting configurations (genetic algorithm)



DECAY PIPE

- Variation of the integrated NuMu fluxes with respect to different Decay Pipe configurations

1st osc. max: $3<E_\nu<6$ GeV

Most probable parent:

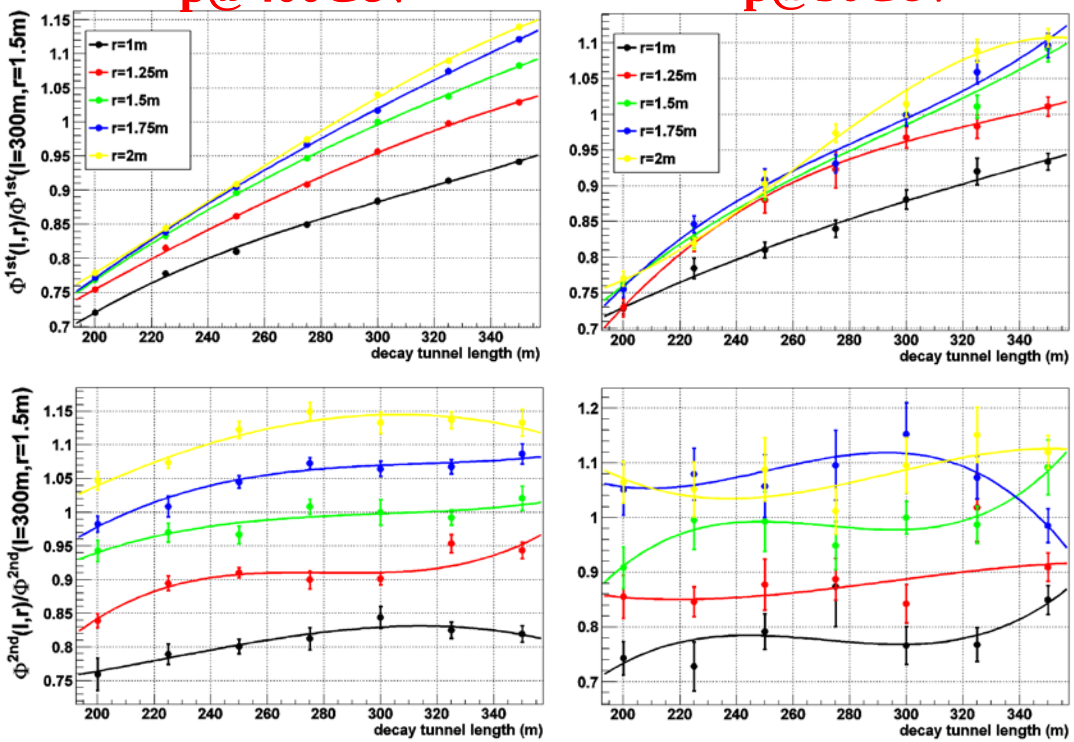
$E_\pi=11$ GeV → $l_d=623$ m

2nd osc. max: $1<E_\nu<2$ GeV

Most probable parent:

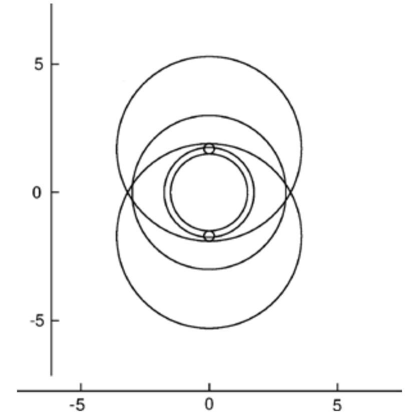
$E_\pi=4$ GeV → $l_d=231$ m

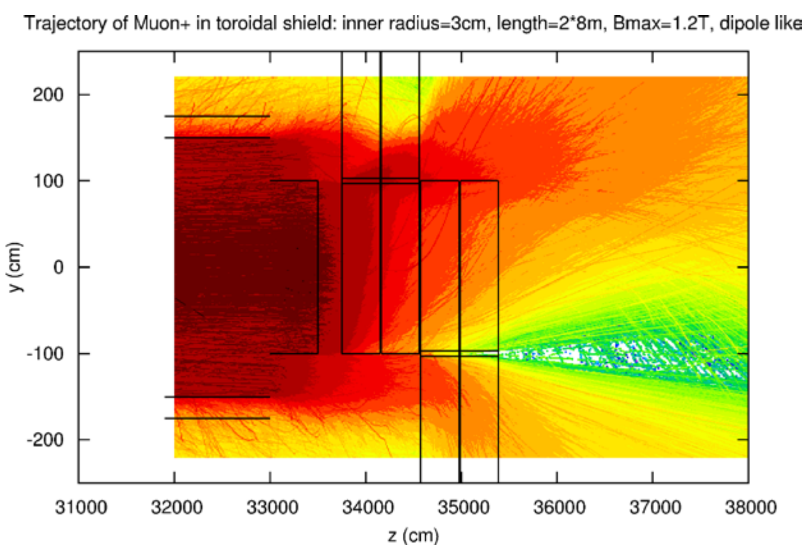
p@400GeV **p@50GeV**

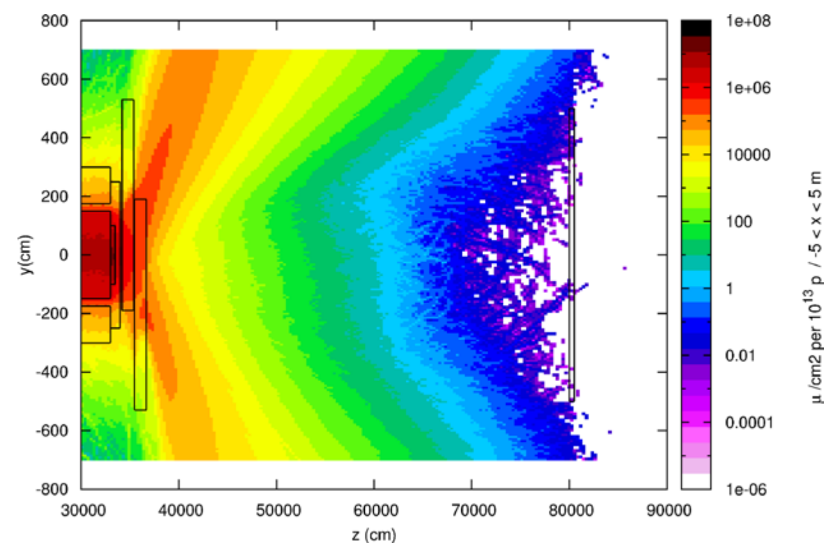


MUON SHIELD

- Active shielding: Double Toroidal magnets
  - Deflecting the muons rather than ranging them out
  - Still requires a significant amount of iron to achieve the required bending power

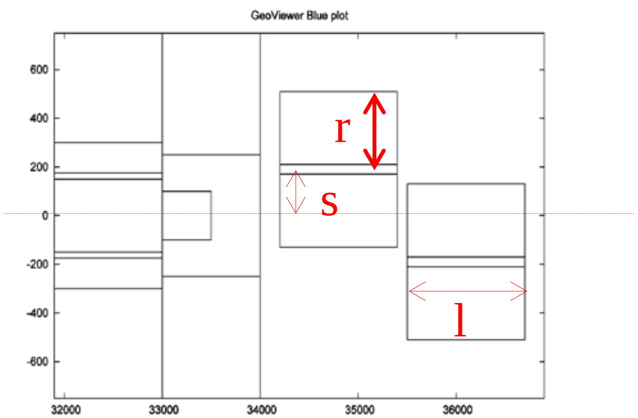


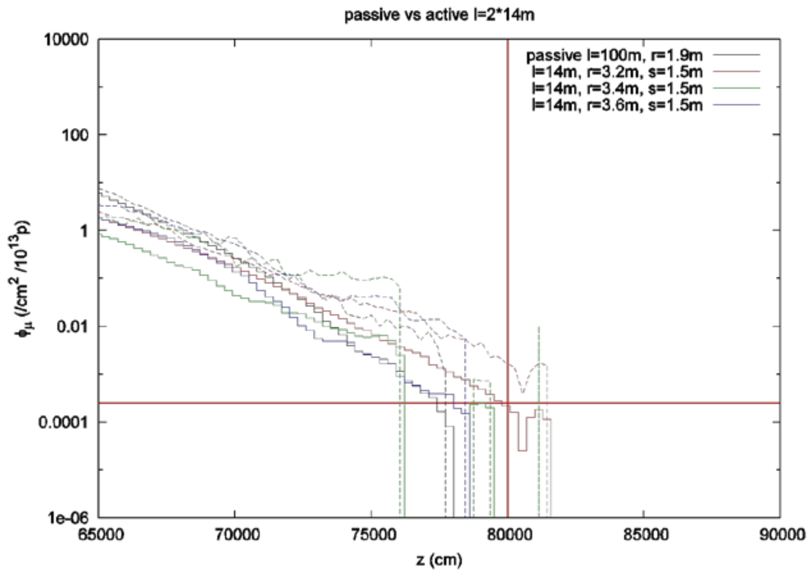




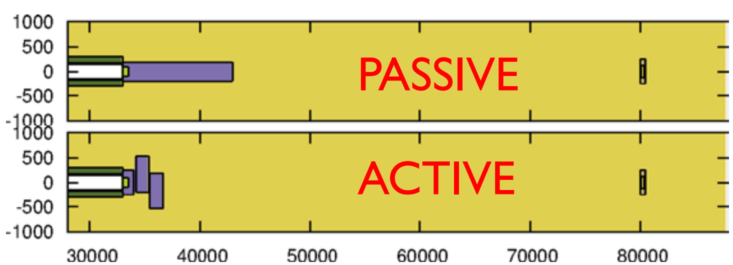
MUON SHIELD

- Active shielding: Double Toroidal magnets





- **Active configuration to match passive shield efficiency : {l=14m, r=3.6m, s=1.5m}**

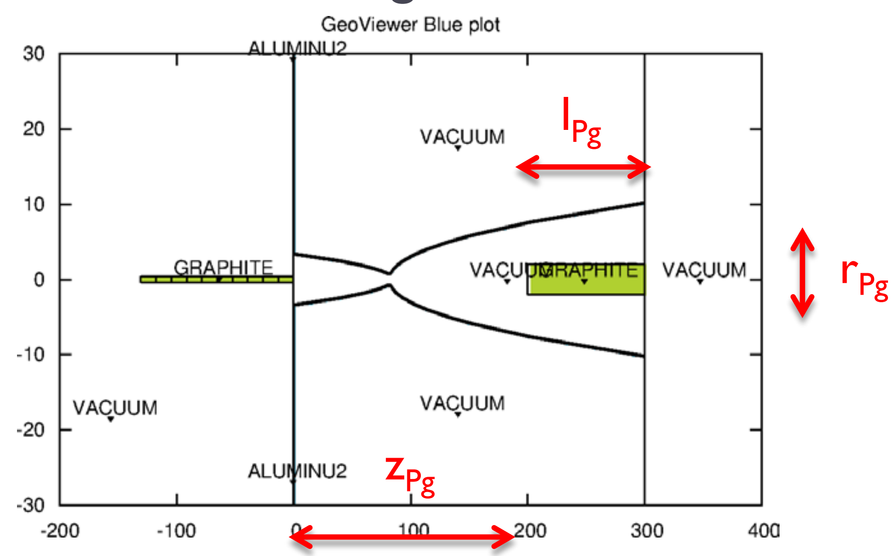


	passive	active
total area density	161 kg/cm ^{2}	126 kg/cm ^{2}
shield length	100 m	28 m
shield diameter	3.8 m	7.2 m
shield volume	1134 m^3	1140 m^3
shield mass	8165 t	8208 t

- Active shielding scenario dismissed for now

High Energy Neutrino Background

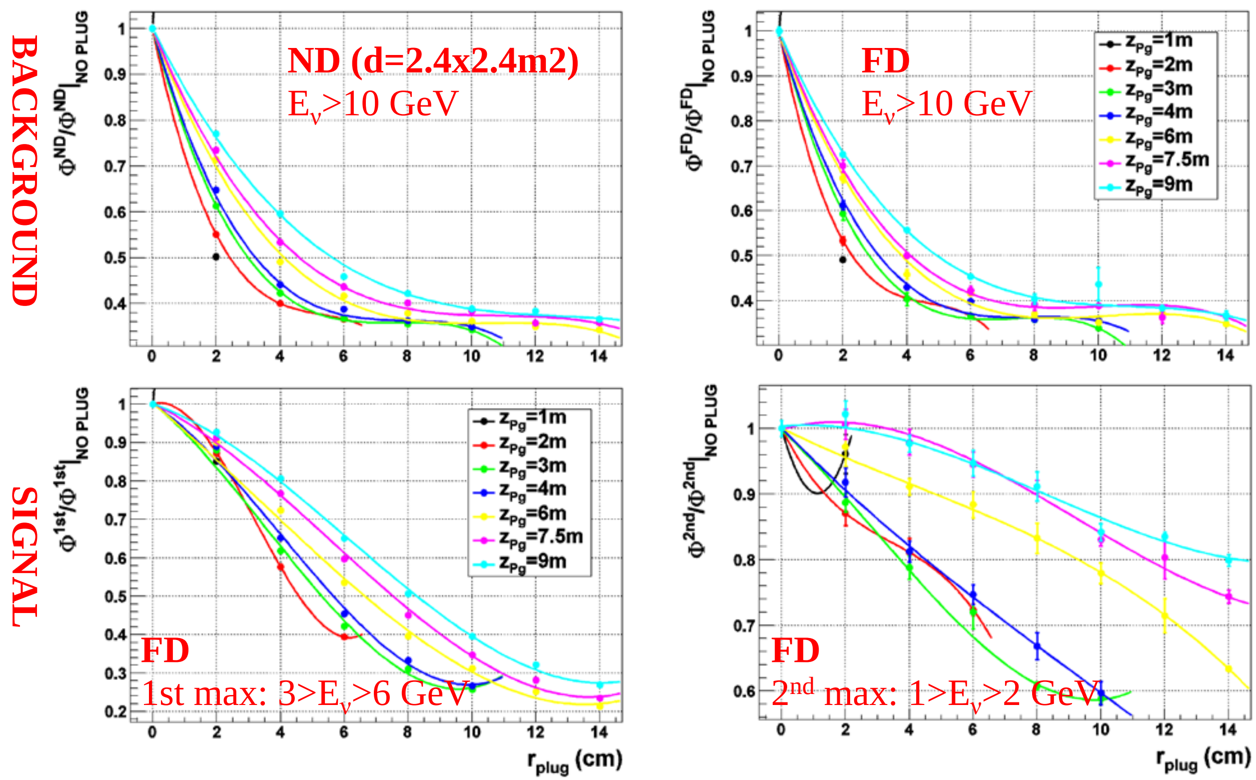
- Neutrinos at **E_ν>10 GeV** are background for both detectors
  - Attempt to suppress the HE part of the secondary beam with a Graphite Plug placed downstream the target



  - Computed the neutrino flux at both detectors for various plug configuration $\{l_{Pg}, r_{Pg}, z_{Pg}\}$

High Energy Neutrino Background

- Results of the plug study for p@400 GeV
  - Fixed length l_{Pg}=1 m



High Energy Neutrino Background

- **Results of the plug study for p@400 GeV**

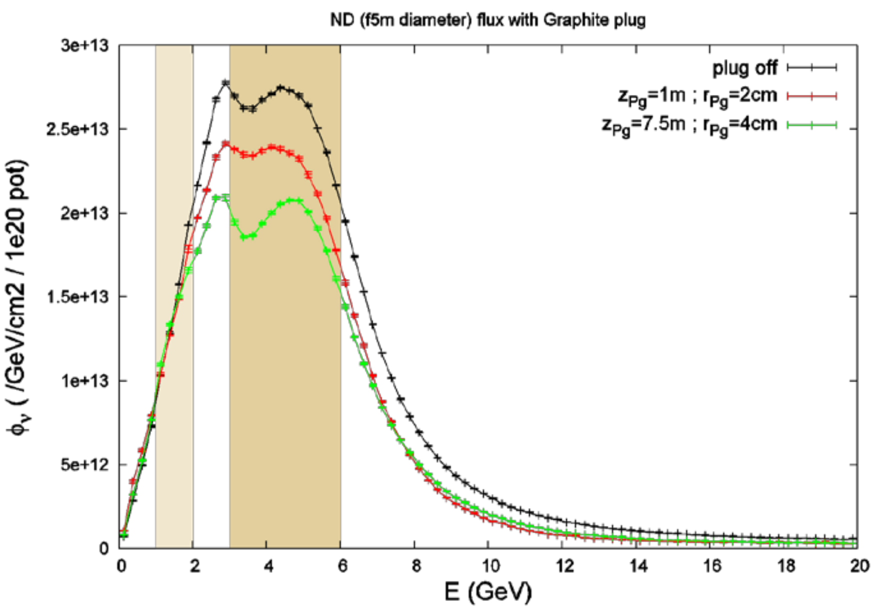
- Selected configurations:
  - $\{z_{Pg}=1\mathrm{m}, r_{Pg}=2\mathrm{cm}\}$: plug located inside the 1st horn
  - $\{z_{Pg}=7.5\mathrm{m}, r_{Pg}=4\mathrm{cm}\}$: plug located between the horns (easier to build ?)

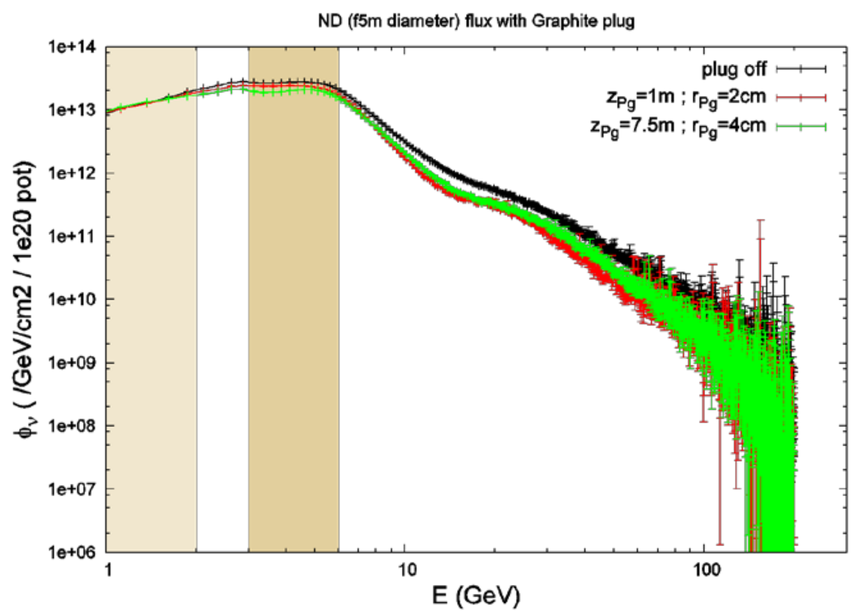
- Efficiencies:
  - 50% reduction in $\Phi(E_\nu>10\mathrm{GeV})$ at both ND and FD
  - 15% (config1) and 24% (config2) reduction for Φ^{1st}, <5% for Φ^{2nd}

- **Is it worth it?**
  - Plug will intercept secondaries + uncollided primary beam
  - Energy deposition such as to require water cooling
  - Other geometries could be investigated (annular design, etc.)

High Energy Neutrino Background

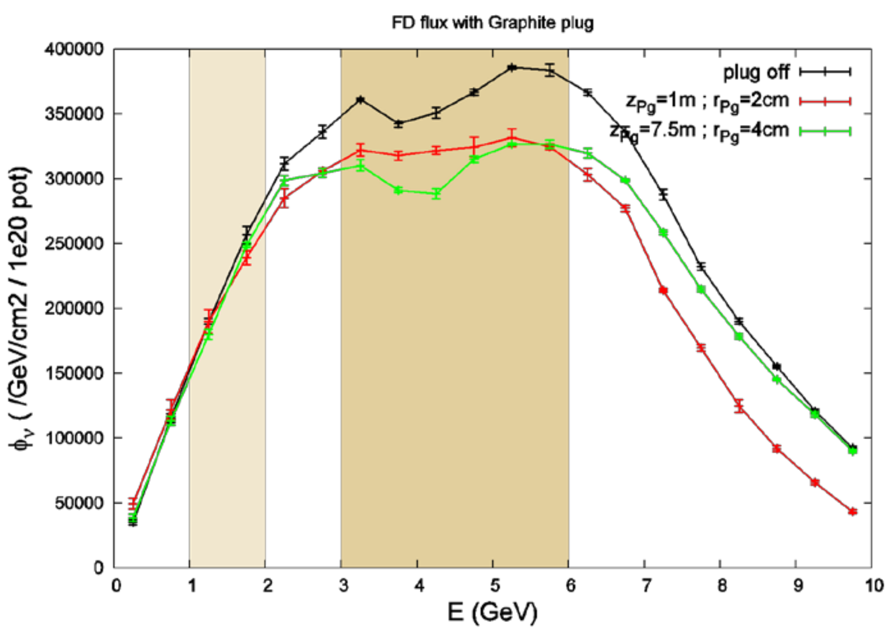
- Results of the plug study for p@400 GeV
  - Graphite Plug – Neutrino spectrum **at NEAR DETECTOR**

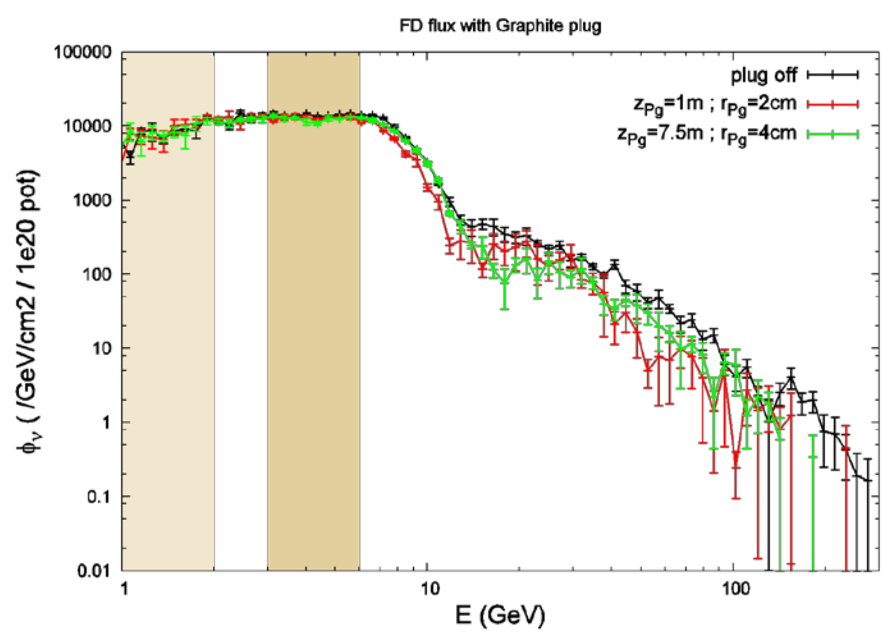




High Energy Neutrino Background

- Results of the plug study for p@400 GeV
  - Graphite Plug – Neutrino spectrum **at FAR DETECTOR**





- Similar studies for **p@50 GeV** under progress