SAND: Status of Samples and Systematics and Aims for the Workshop

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DUNE Oscillation Analysis Workshop

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INFN GENOVA

DUNE

SAND in a LBL analysis

- Past TDR-era analysis: SAND used «implicitly» to assume the time stability of the beam.
- Next round needs to integrate inputs from all ND components, including SAND.
- This workshop is a «**kick-off**» meeting for SAND, lots of discussion needed
  - **Goals**: to which level SAND can contribute to LBL
  - **Systematics**: which ones can SAND help with
  - **Technical**: getting to know LBL tools, approach, fitters, data formats

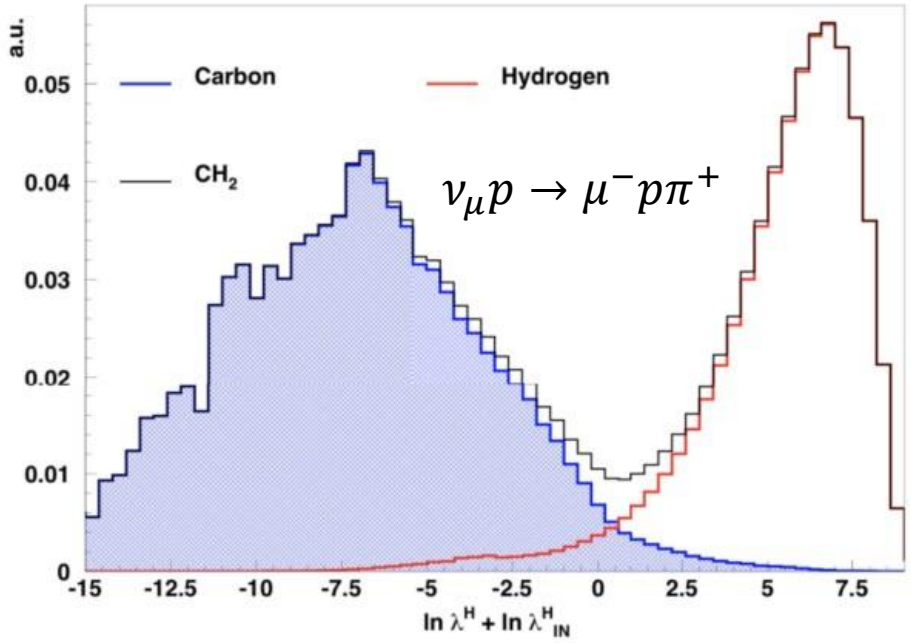
LBL inputs from SAND

- Evaluating systematics
  - Beam monitoring → reduce **flux systematics** related to beam alignment, target parameters.
  - C, CH_2, Ar (+H) targets → constrain directly **cross-section parameters**, interaction modeling
  - Wrong-sign background evaluation.

- Precise flux measurements
  - **Relative $\nu_\mu, \bar{\nu}_\mu$ fluxes** from interactions on H
  - ν_μ/ν_e, $\bar{\nu}_\mu/\bar{\nu}_e$ and $\nu_\mu/\bar{\nu}_\mu$ ratios (from C, CH_2)
- ν-Ar interactions
  - inclusive/exclusive **ν-Ar CC samples** inside B field

H samples

- ν-H interactions from statistical subtraction of **CH_2 and C** data.
  - Probe into nuclear effects by comparison with other targets (C, Ar,...)
  - Relative $\nu_\mu, \bar{\nu}_\mu$ flux vs E via $\nu_\mu p \to \mu^- p\pi^+$ and $\bar{\nu}_\mu p \to \mu^+ n$ (< 1%)



CC process (1y+1y)	H selected Evts/year
$\nu_\mu p \to \mu^- p\pi^+$	408,000
$\nu_\mu p \to \mu^- p\pi^+ X$	152,000
$\nu_\mu p \to \mu^- n\pi^+\pi^+ X$	19,000
ν_μ CC inclusive on H	579,000
$\bar{\nu}_\mu p \to \mu^+ n$	172,000
$\bar{\nu}_\mu p \to \mu^+ p\pi^-$	61,000
$\bar{\nu}_\mu p \to \mu^+ n\pi^0$	42,000
$\bar{\nu}_\mu p \to \mu^+ p\pi^- X$	27,000
$\bar{\nu}_\mu p \to \mu^+ n\pi\pi X$	31,000
$\bar{\nu}_\mu$ CC inclusive on H	333,000

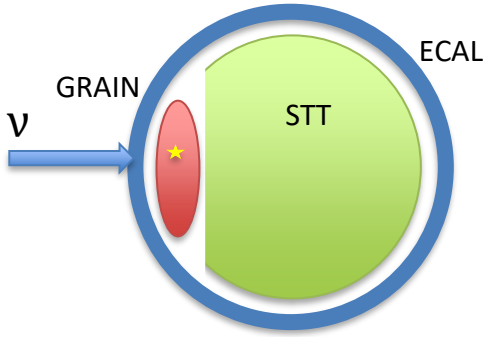
arXiv:1809.08752 [hep-ph]

$\nu_\mu/\bar{\nu}_\mu$ ratio

- SAND is magnetized → μ^-/μ^+ separation.
- Estimation of background from **wrong-sign contamination** (especially relevant for RHC mode)

- For example: Coherent π^-/π^+ production on C ?
  - Same signature ($\mu^+\pi^-$ or $\mu^-\pi^+$) → selection systematics cancel out in the ratio
  - C is isoscalar nucleus: same cross-section for neutrinos and antineutrinos → some model systematics cancel
  - Constraint on the $\nu_\mu/\bar{\nu}_\mu$ ratio at 4-7%

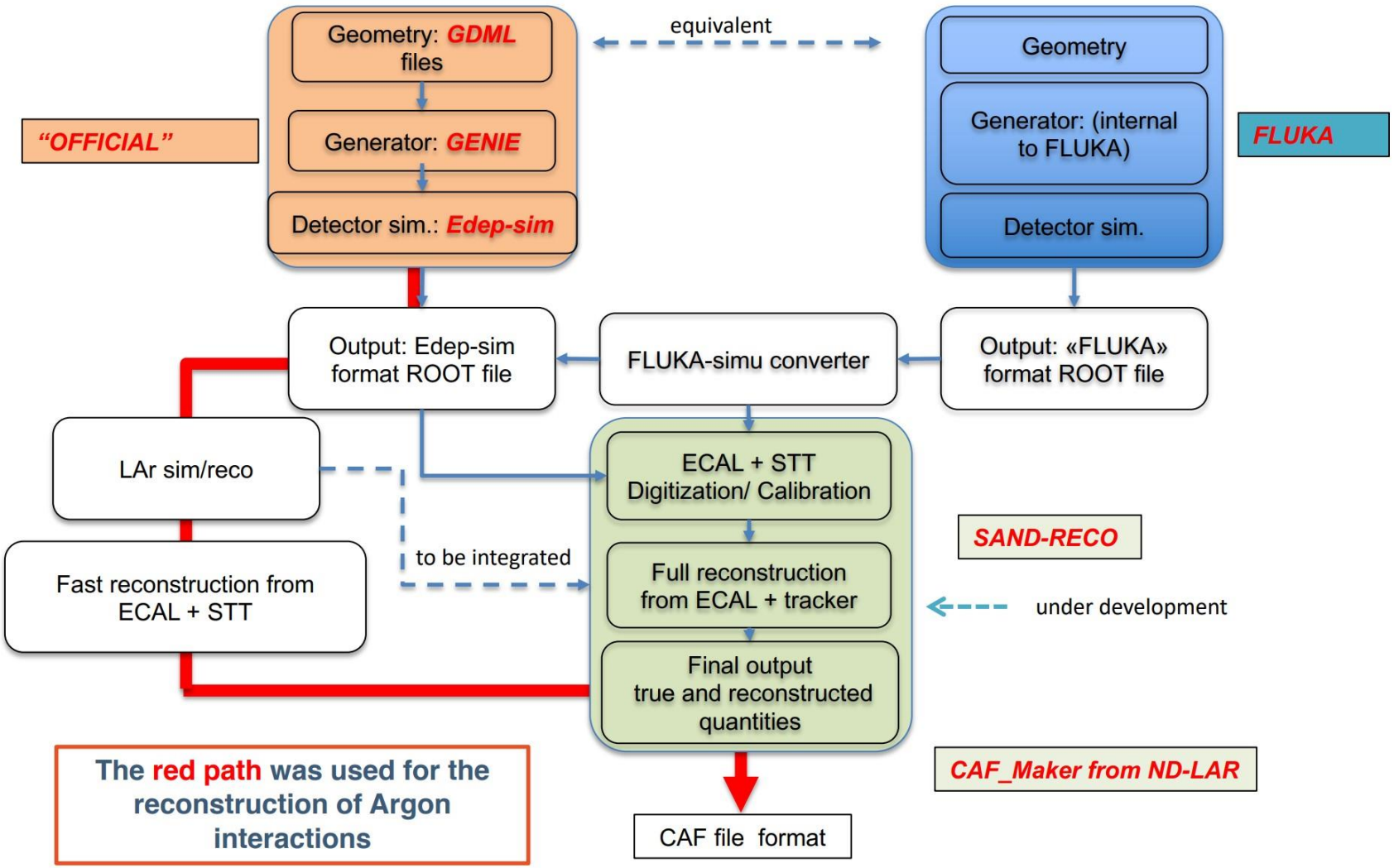
LAr samples



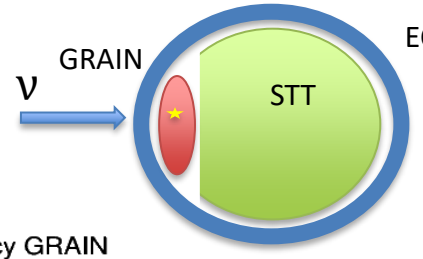
- Neutrino interactions in **GRAIN**
  - Ar cross-sections/nuclear effects, comparing with other targets (H)
  - CC samples for LBL fit (only interaction variables)
- Lots of efforts recently to integrate GRAIN optical simulation/reconstruction in general SAND framework.

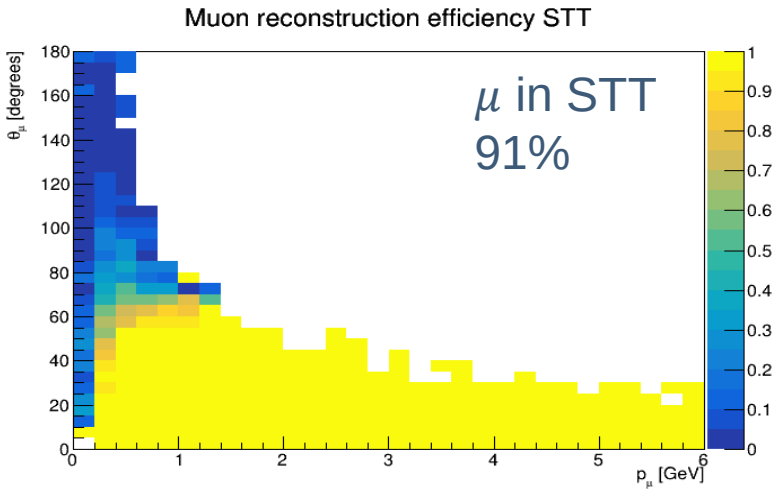
- Moderate FHC statistics file currently available ($\sim 10^5$ events) [1 yr. FHC $\sim 12 \cdot 10^6$evts]
  - Propagation: EDepSim + optical simu (OptMen)
  - Reco: GRAIN reco (lar-lenses) + FastReco w/ GRAIN input

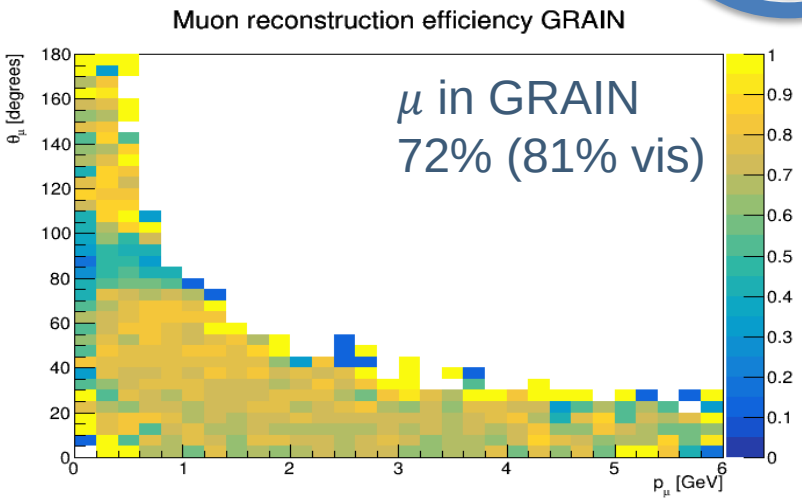
Software flowchart

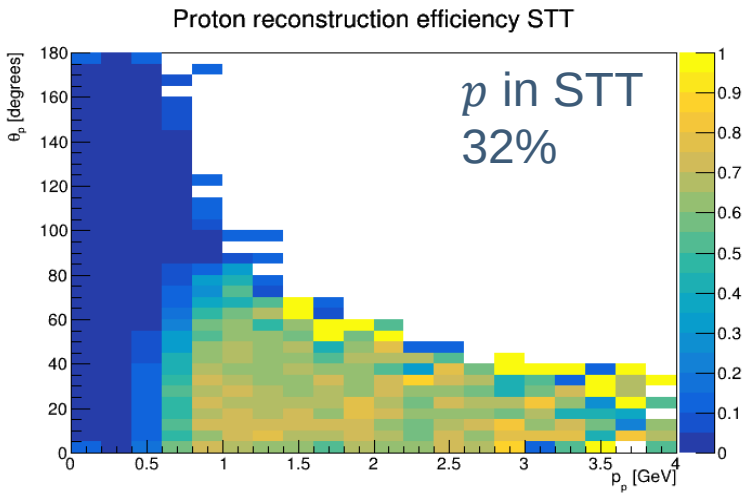


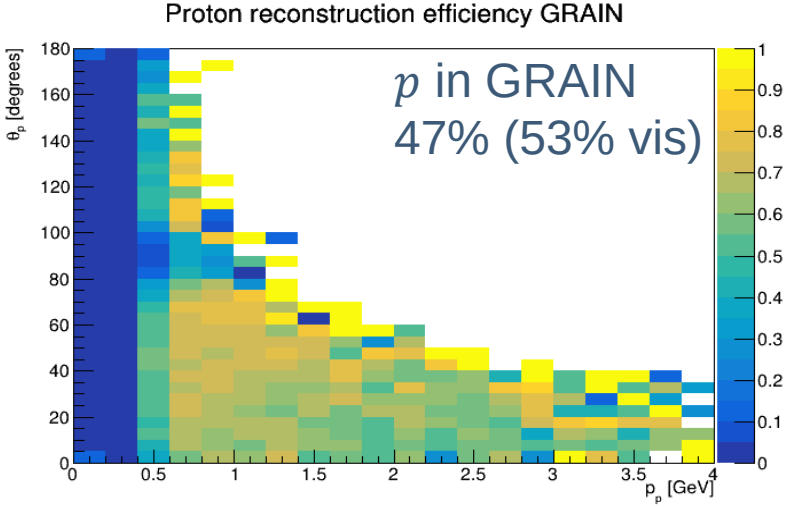
LAr samples







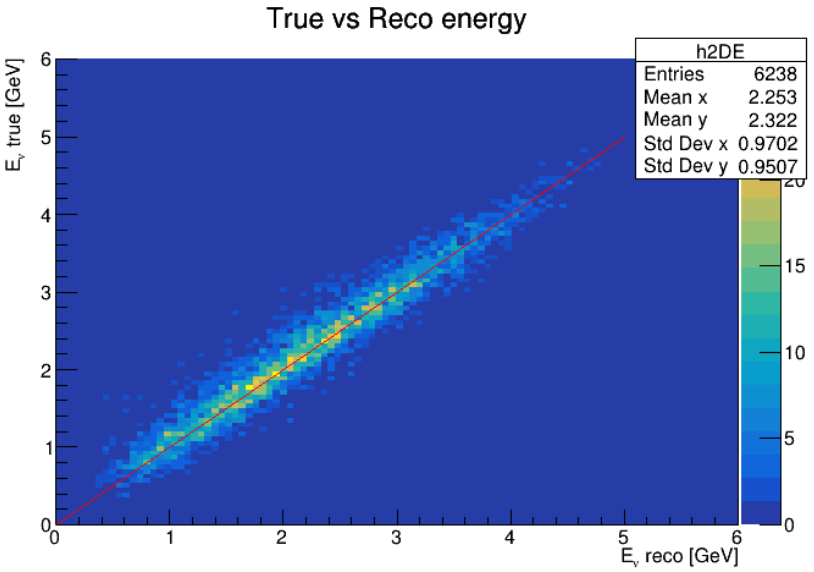


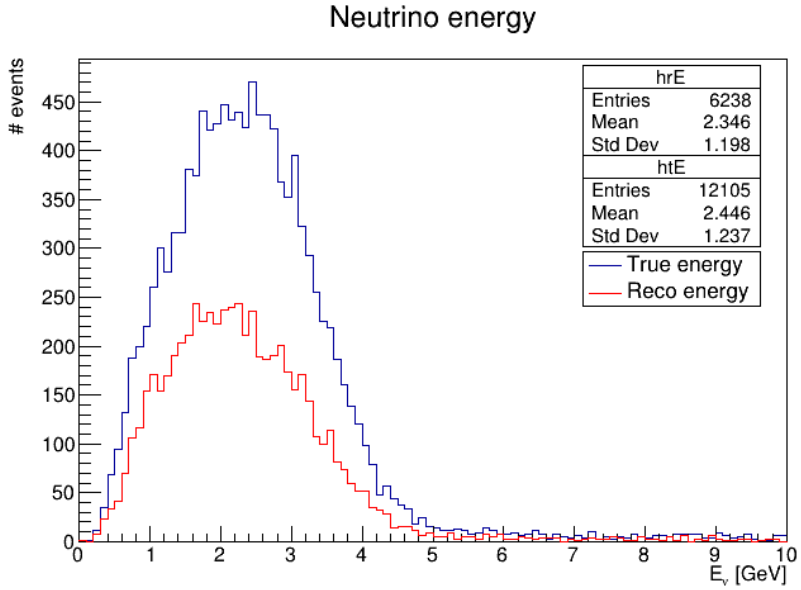


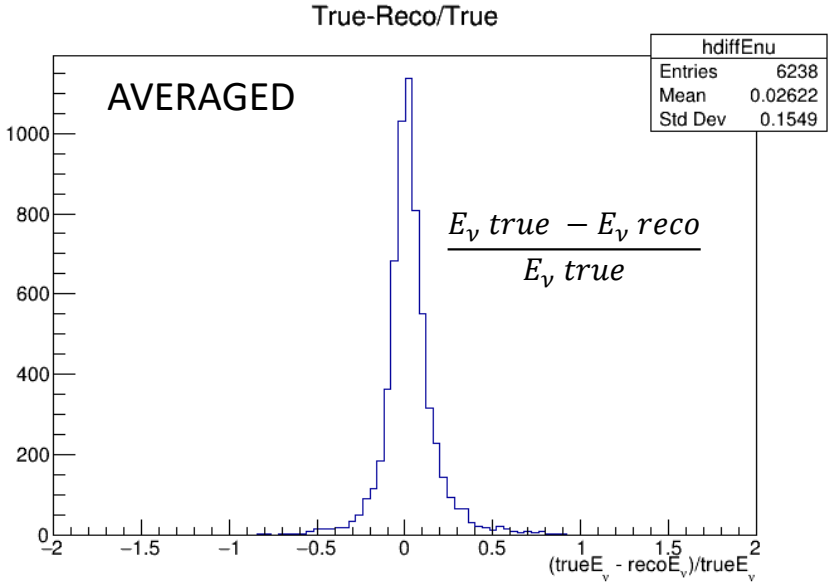
*Issue at 90° is a current limitation of the reco algorithm in GRAIN

LAr samples

- Esclusive $0\pi\ Np$ channel extracted at GENIE-level (no neutrons)
- Reco'ed events:
  - vertex seen by GRAIN in FV
  - OR at least 2 tracks in STT







CAF format

- SAND branch within ND_CAFMaker.
- https://github.com/DUNE/ND_CAFMaker/tree/sandcaf
- Currently only filling truth variables + some high level reco variables already present. More will be added as needed.

RECO INFO		
float	Ev_reco	in SANDRecoBranchFiller
int	reco_lepton_pdg	in SANDRecoBranchFiller
float	Elep_reco	in SANDRecoBranchFiller
int	reco_numu	in SANDRecoBranchFiller
int	reco_nue	in SANDRecoBranchFiller
int	reco_nc	in SANDRecoBranchFiller
float	eRecoP	in SANDRecoBranchFiller
float	eRecoN	in SANDRecoBranchFiller
float	eRecoPip	in SANDRecoBranchFiller
float	eRecoPim	in SANDRecoBranchFiller
float	eRecoPi0	in SANDRecoBranchFiller
float	eRecoOther	in SANDRecoBranchFiller

+ all truth variables

Workshop goal: SAND systematics

- Strong effort is needed from SAND people to implement detector systematics.
- Identification/clarification of relevant LBL systematics.

Possible SAND detector systematics:

- Reconstruction systematics:
  - GRAIN energy calibration and hadron ID
  - ECAL calibration and ID
  - STT momentum calibration (K_{0_S}, Λ^0)
- Selection and «phase-space» systematics

Workshop goal: General

- Much discussion needed!

- Get to know the steps of a LBL analysis:
  - Identify relevant systematics
  - Choose a physics objective → develop a selection + systematics.

- Prioritize inputs from SAND: short term vs long term

Backup

Expected rates

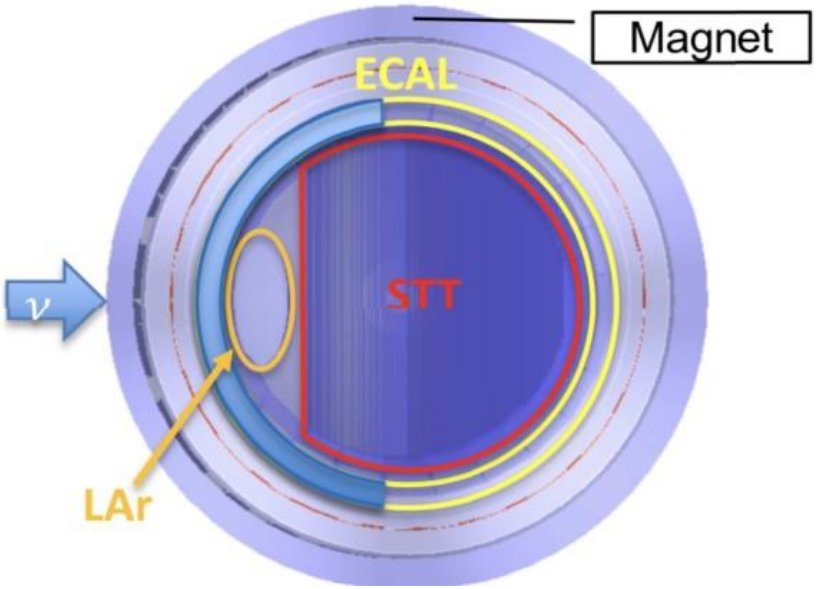
Target	CP optimized FHC (1.2MW, 2y)				CP optimized RHC (1.2MW, 2y)			
	ν_μ CC	$\bar{\nu}_\mu$ CC	ν_e CC	$\bar{\nu}_e$ CC	ν_μ CC	$\bar{\nu}_\mu$ CC	ν_e CC	$\bar{\nu}_e$ CC
CH_2	13,010,337	624,330	192,118	31,902	2,035,973	4,870,562	91,004	69,278
H	1,222,576	111,574	18,396	5,557	194,216	906,130	8,712	12,434
C	1,547,011	67,294	22,799	3,458	241,710	520,287	10,800	7,460
Ar	3,114,331	121,506	46,384	6,503	480,862	936,489	21,932	13,867
Pb	62,127,600	2,507,940	923,012	130,680	10,375,400	18,222,200	437,284	265,304

NOTE: 100 kt-MW-years in Phase I FD corresponds to about 2y FHC + 2y RHC with 1.2 MW beam

STT FV mass:
4.7 t CH_2
557 kg C

GRAIN mass:
1 t LAr

Front ECAL mass:
22.8 t Pb



$\nu_\mu/\bar{\nu}_\mu$ ratio

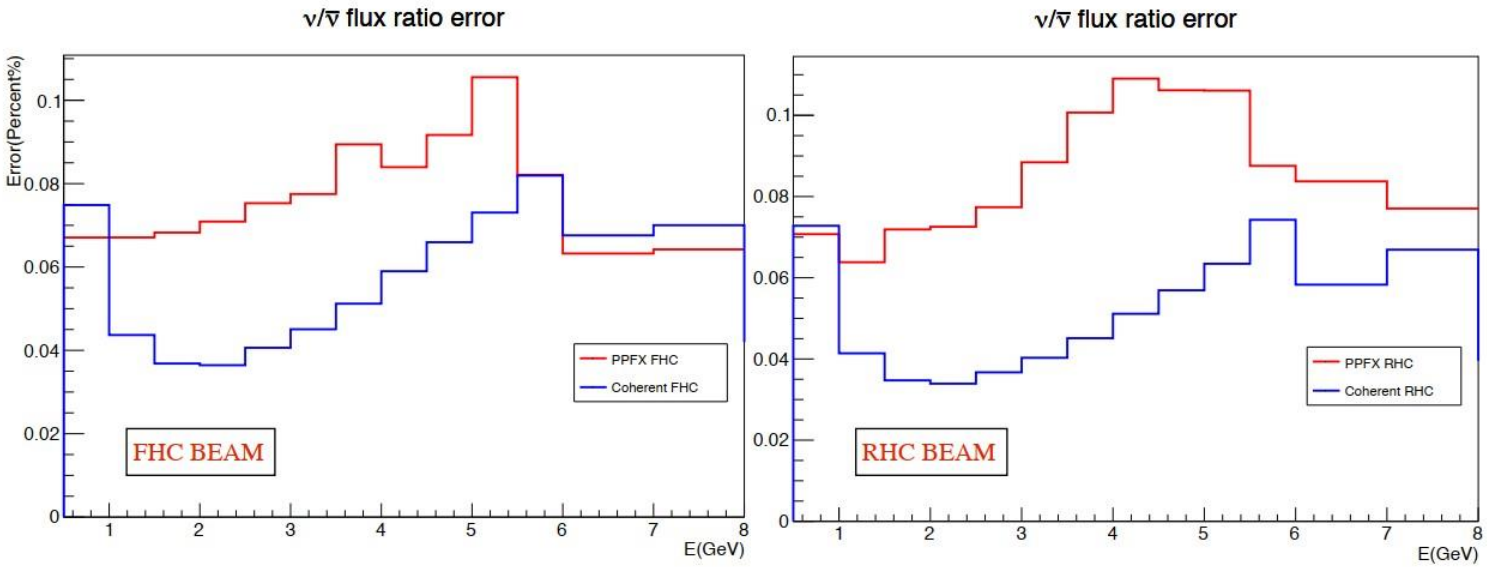


Figure 208: Uncertainty on the $\bar{\nu}_\mu/\nu_\mu$ flux ratio determined in STT from the ratio of coherent pion production in both the neutrino FHC (left panel) and antineutrino RHC (right panel) beam polarities. The corresponding uncertainties obtained from the beam simulation group are also shown for comparison.

DUNE-doc-13262, p. 144

FastReco

- For charged particles, information from GRAIN, STT and ECAL depending on what is available.
  - **GRAIN**: image-based reco w/ lenses for vertex and 3D direction, 20% smear on true energy deposit.
  - **STT**: min 6 hits in ZY planes, Gluckstern formula on momentum at STT entrance.
  - **ECAL**: 100 KeV threshold for cell, smear according to KLOE published performance.
- Loops through primary particles, summing up their 4-momentum to compute back E_ν.
- Event reconstructed → at least one of two conditions:
  - Vertex is found in GRAIN reco (w/ images)
  - At least 2 tracks in STT
- No particle identification.