This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 681647).

The ENUBET experiment for high precision neutrino cross section measurements

A. Branca (on behalf of the ENUBET Collaboration) - University of Milano-Bicocca & INFN

TAUP VIENNA 2023

XVIII International Conference on Topics in Astroparticle and Underground Physics

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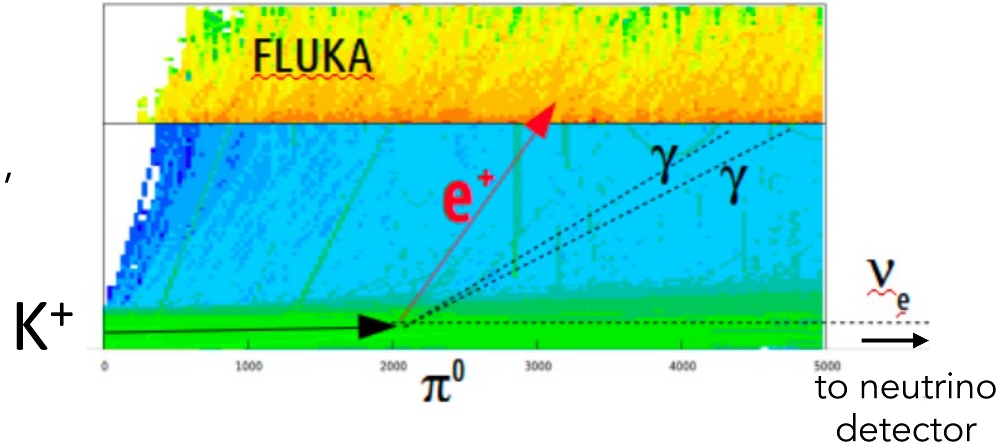
Outline

- ENUBET is the project for the realization of the first monitored neutrino beam.
  - ENUBET: ERC Consolidator Grant, June 2016 – May 2021 (COVID: extended to end 2022). PI: A. Longhin;
  - Since April 2019: CERN Neutrino Platform Experiment – NP06/ENUBET – and part of Physics Beyond Colliders (PBS);
  - Collaboration: 72 physicists & 15 institutions; Spokespersons: A. Longhin, F. Terranova; Technical Coordinator: V. Mascagna;



- In the next slides:
  - Final design of the beamline;
  - Particle identification performance and lepton monitoring impact on neutrino flux systematics;
  - First results from final prototype test-beam;
  - Plans for beamline implementation in the CERN North Area

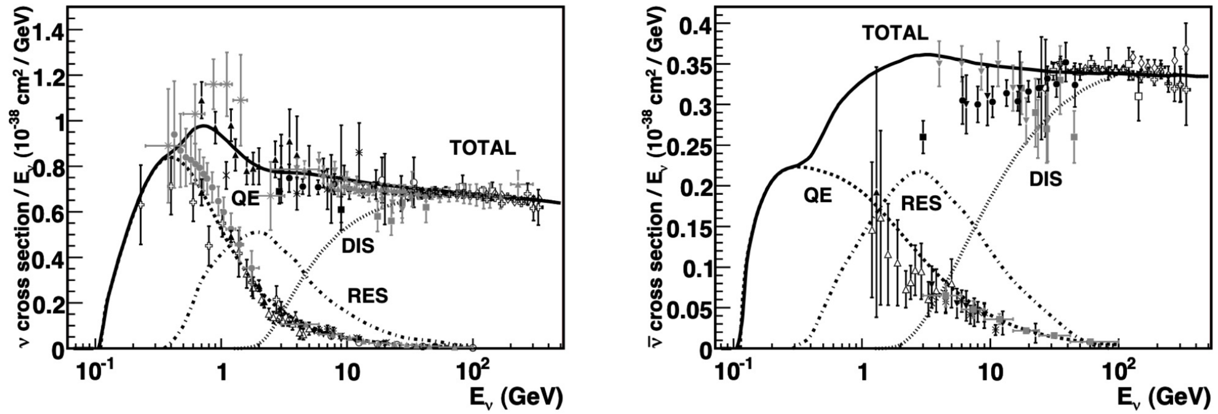
Visit our webpage/social for further info and material!

WEB https://www.pd.infn.it/eng/enubet/

twitter @enubet

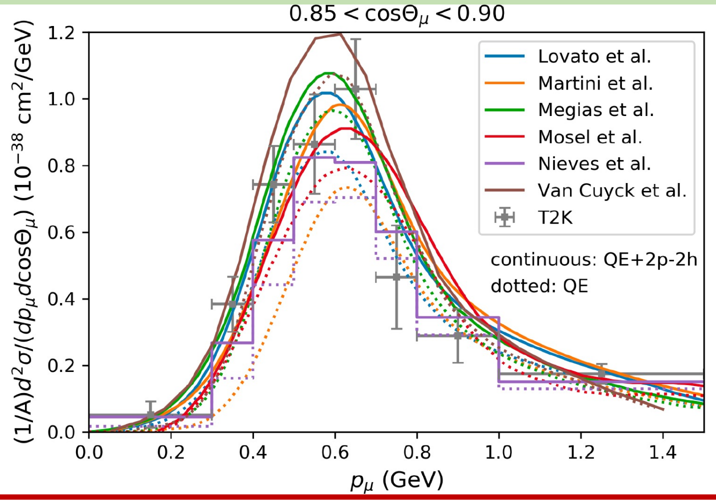
A precision era for neutrino-nucleus interactions

Total $\nu_\mu/\bar{\nu}_\mu$ cross section per nucleon



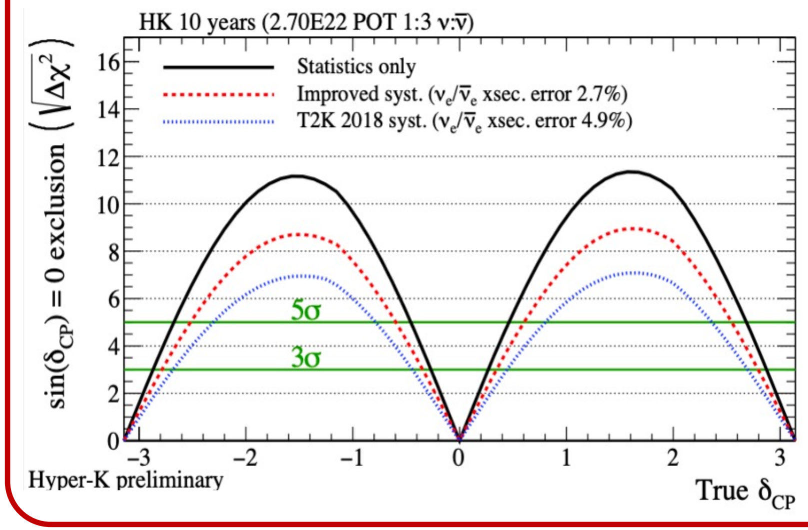
Fight large errors

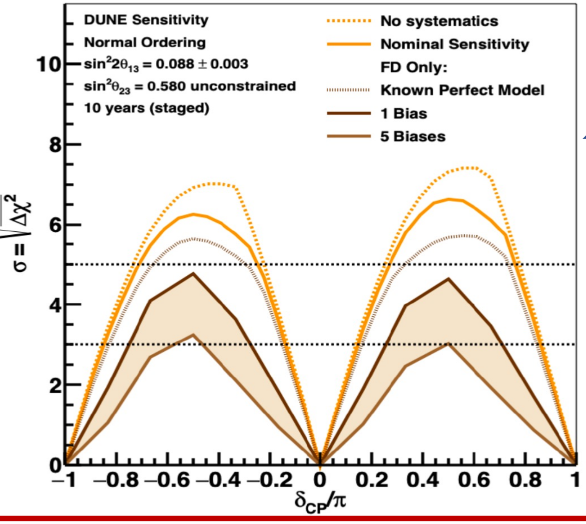
Double-diff. ν_μ cross section: data (T2K) VS models



Disentangle different models

HK (left) and DUNE (right) sensitivity to CP phase





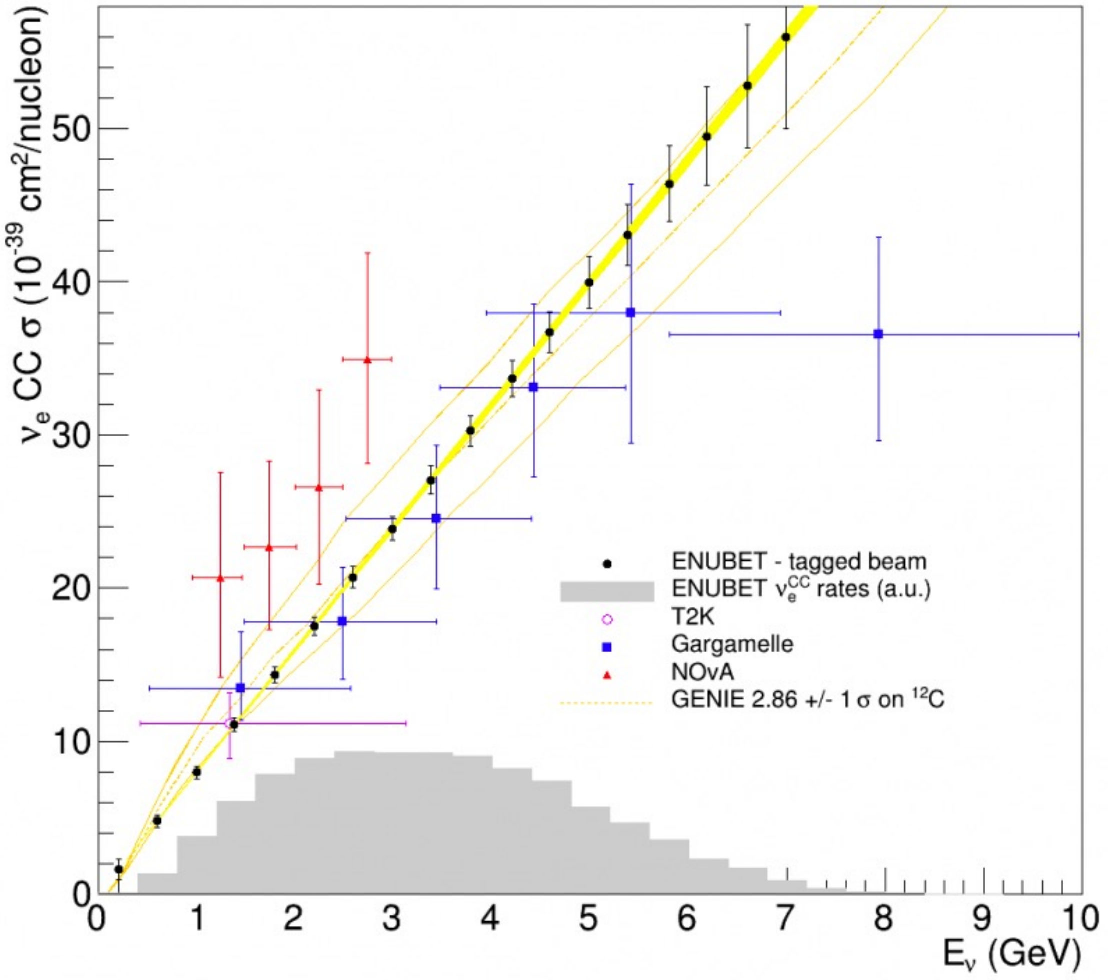
Boost sensitivity

Precision measurements of the neutrino cross sections are beneficial for:

- Improving theoretical knowledge: allow to disentangle different neutrino interaction models;
- Next generation long-baseline experiments: boost in the sensitivity to the neutrino oscillation parameters;

The aim of the ENUBET project

ENUBET impact on ν_e cross section



The purpose of ENUBET: design a narrow-band neutrino beam to measure

- neutrino cross-section and flavor composition at 1% precision level;
- neutrino energy at 10% precision level;

From the **European Strategy for Particle Physics Deliberation document**:

To extract the most physics fromDUNE and Hyper-Kamiokande, a complementary programme of experimentation to determine neutrino cross-sections and fluxes is required. Several experiments aimed at determining neutrino fluxes exist worldwide. The possible implementation and impact of a facility to measure neutrino cross-sections at the percent level should continue to be studied.

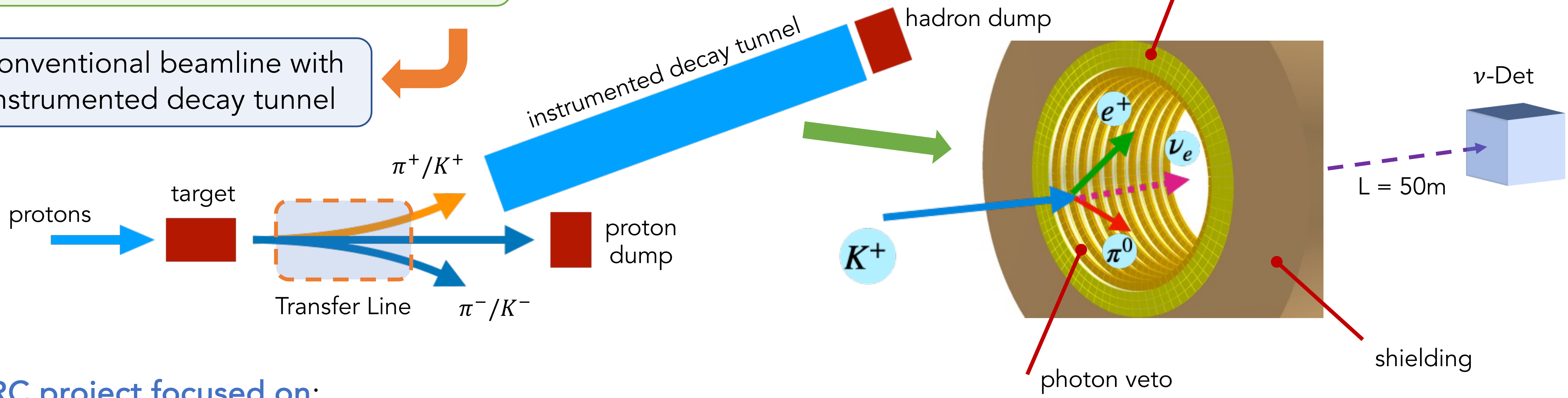
ENUBET: the first monitored neutrino beams

How do we achieve such a precision on the neutrino cross-section, flavor composition and energy?

Monitored ν flux from narrow-band beam
measure rate of leptons ⇔ monitor ν flux

Conventional beamline with instrumented decay tunnel

A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155



- **ERC project focused on**:
  measure positrons (instrumented decay tunnel) from K_{e3} ⟹ determination of ν_e flux;
- **As CERN NP06 project**:
  extend measure to muons (instrumented decay tunnel) from $K_{\mu\nu}$ and (replacing hadron dump with range meter) $\pi_{\mu\nu}$ ⟹ determination of ν_μ flux;

Main systematics contributions are bypassed: hadron production, beamline geometry & focusing, POT;

The ENUBET beamline: the final design

ENUBET Collab., Design and performance of the ENUBET monitored neutrino beam -> arXiv:2308.09402 [hep-ex]

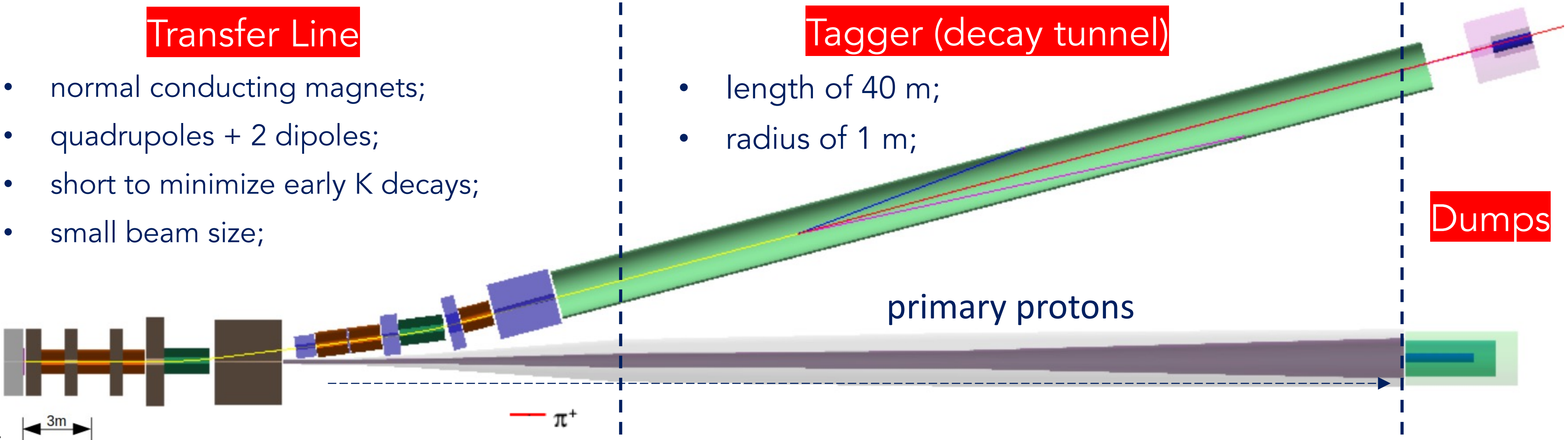
Transfer Line

- normal conducting magnets;
- quadrupoles + 2 dipoles;
- short to minimize early K decays;
- small beam size;

Tagger (decay tunnel)

- length of 40 m;
- radius of 1 m;

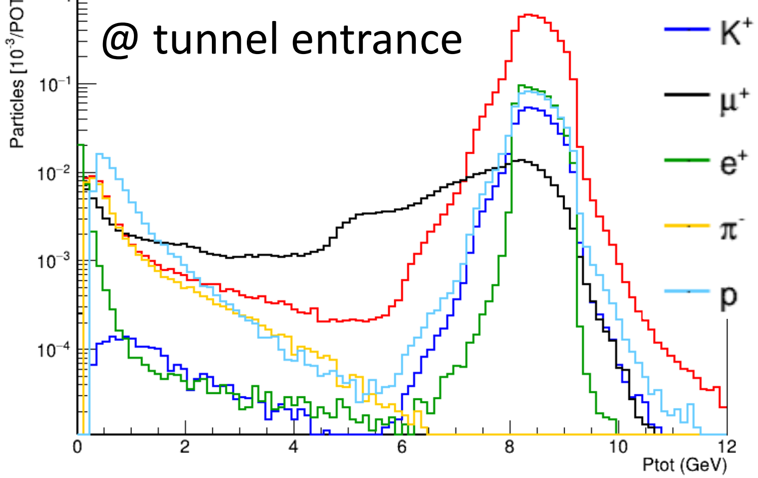
Dumps



Full facility implemented in GEANT4:

- Controll over all paramaters;
- Access to the paricles histories;

assessment of the nu flux systematics



π^+ $[10^{-3}]$/POT	K^+ $[10^{-3}]$/POT
4.6	0.4

Large bending angle of 14.8°:

- better collimated beam + reduced muons background + reduced ν_e from early decays;

Transfer Line:

- optics optimization w/ **TRANSPORT, G4Beamline + GEANT4** particle transport/interactions;
- **FLUKA** for irradiation studies, **absorbers and rock** volumes included in simulation;
- **optimized graphite target** 70 cm long & 3 cm radius (dedicated studies);
- **tungsten foil downstream target** to suppress positron background (optimized thick);
- tungsten alloy **absorber @ tagger entrance** to suppress backgrounds;

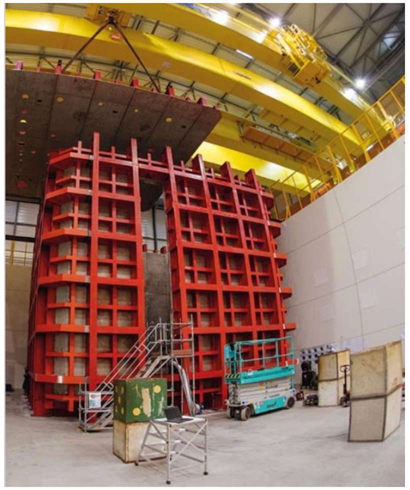
Dumps:

- **Proton dump**: three cylindrical layers (graphite core -> aluminum layer -> iron layer);
- **Hadron dump**: same structure of the proton dump -> reduced backscattering flux in tunnel;

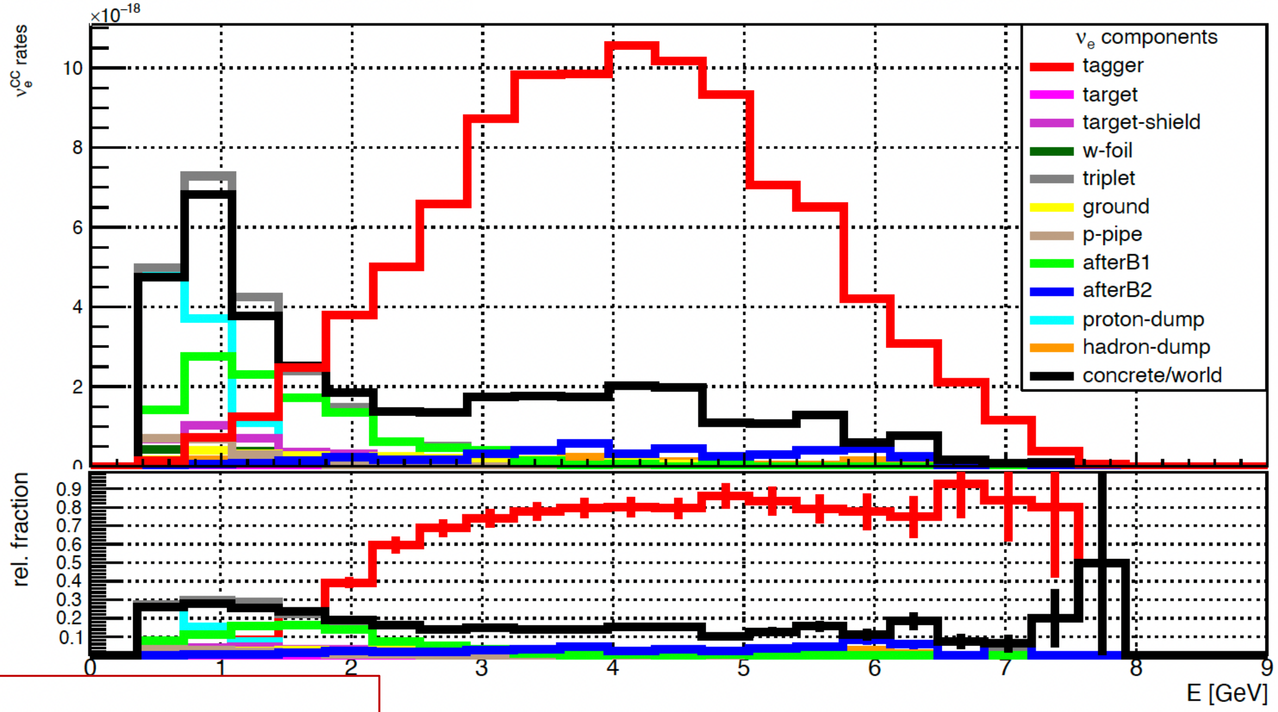
ν_e^{CC} energy distribution @ detector

A total ν_e^{CC} statistics of 10^4 events in ~2.3 years

- @ SPS with $4.5 \cdot 10^{19}$ POT/year;
- 500 ton detector @ 50 m from tunnel end;



ν_e CC spectra



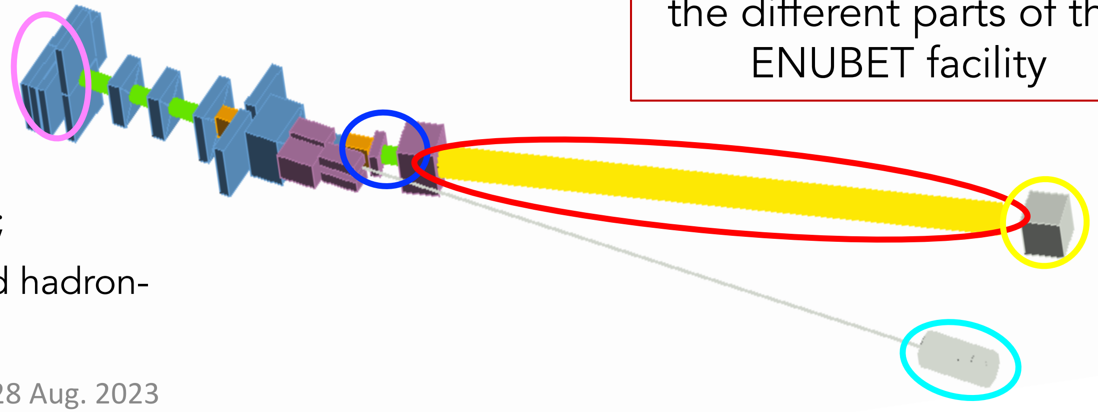
Taggable component

About 68% of total ν_e flux is produced by decays in the tunnel (above 1.5 GeV)

Non taggable components:

- **Below 1.5 GeV**: main component produced in p-dump
  - clear separation from taggable ones (energy cut);
  - further improvements in separation optimizing p-dump position;
- **Above 1.5 GeV**: contributions from straight section before tagger and hadron-dump: rely on simulation for this component;

Contributions to ν_e^{cc} from the different parts of the ENUBET facility



ν_μ^{CC} energy distribution @ detector

Narrow-band off-axis Technique

Narrow momentum beam O(5-10%)

(E_ν,R) are strongly correlated

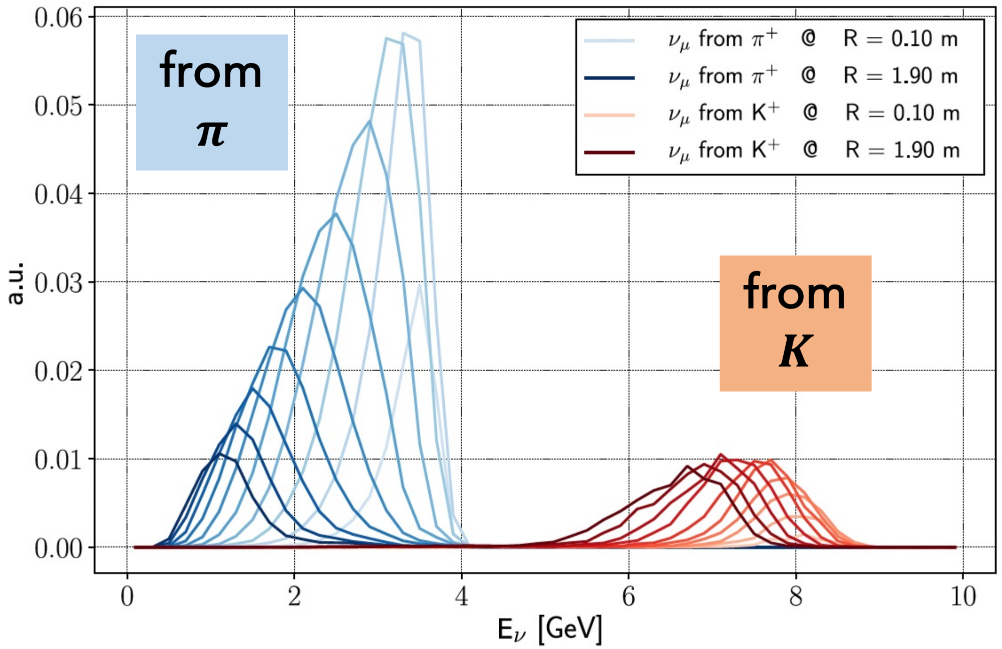
E_ν = neutrino energy;

R = radial distance of interaction vertex from beam axis;

Precise determination of E_ν:

no need to rely on final state particles from ν_μ^{CC} interaction

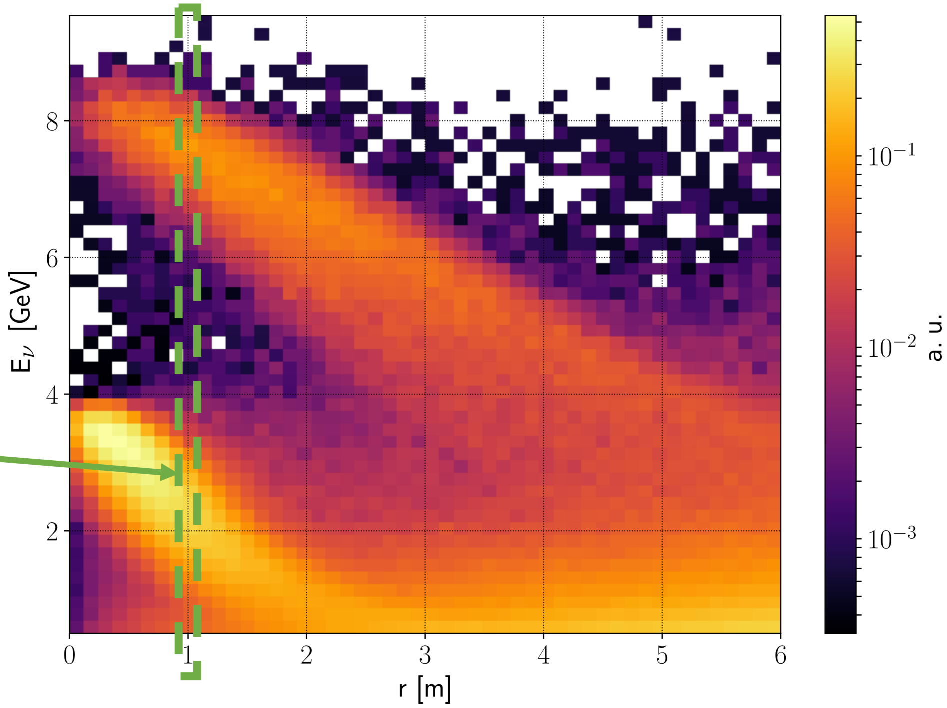
- 10-25% E_ν resolution from π in DUNE energy range;
- ongoing R&D: Multi-Momentum Beamline (4.5, 6 and 8.5 GeV) => HyperK & DUNE optimized;



π/K populations well separated

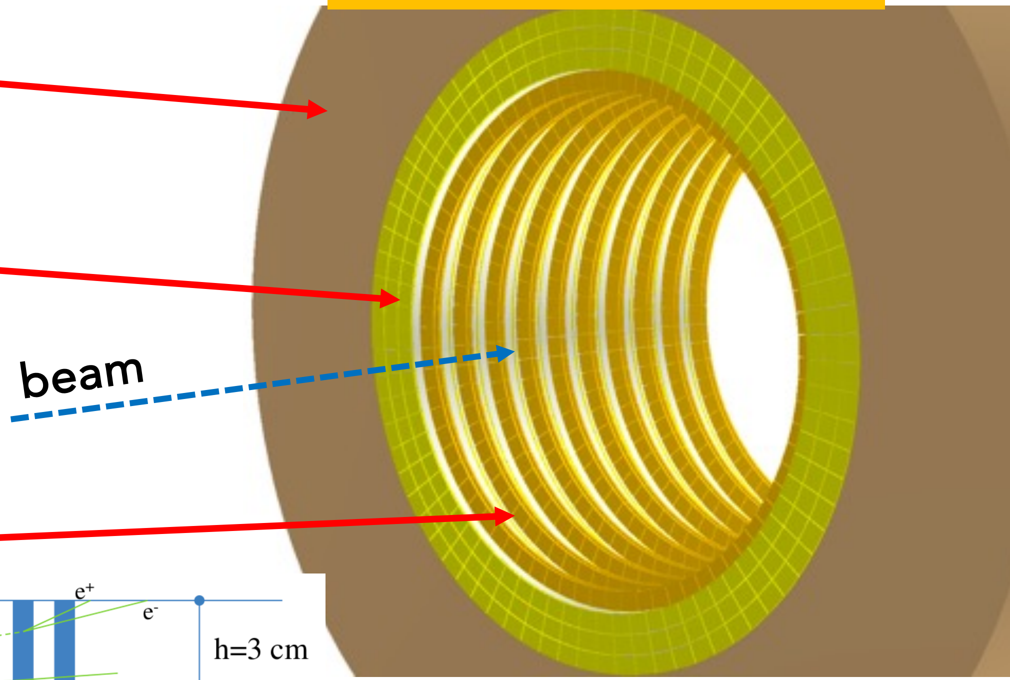
Select ν_μ with given energy by performing cut on R

All ν_μ^{CC}: backgroun @ low E and high R



Decay tunnel instrumentation

Calorimeter layout



Shielding

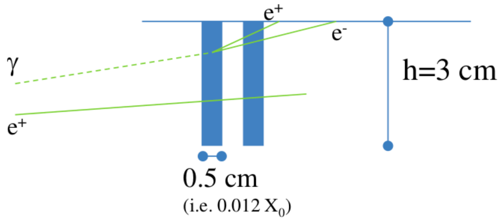
- 30 cm of borated polyethylene;
- SiPMs installed on top -> factor 18 reduction in neutron fluence;

Calorimeter with $e/\pi/\mu$ separation capabilities:

- sampling calorimeter: sandwich of plastic scintillators and iron absorbers;
- three radial layers of LCM / longitudinal segmentation;
- WLS-fibers/SiPMs for light collection/readout;

Photon-Veto allows π^0 rejection and timing:

- plastic scintillator tiles arranged in doublets forming inner rings;
- time resolution of ~400 ps;



Exploit event topology for PID


e^+ (signal) topology


π^0 (background) topology


π^+ (background) topology

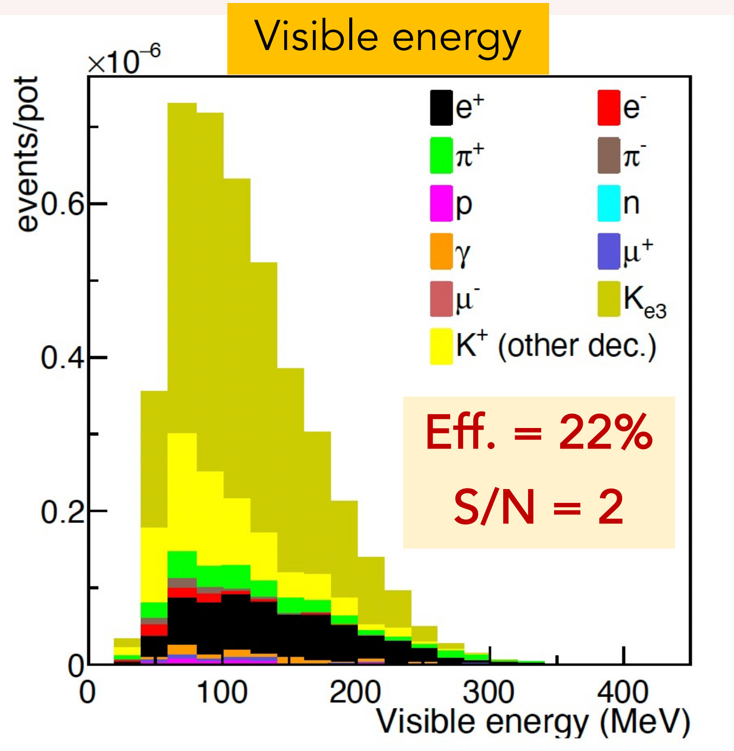

μ^+(signal/bkg) topology

Lepton reconstruction and identification performance

✓ **Full GEANT4 simulation of the detector**: validated by prototype tests at CERN in 2016-2018; hit-level detector response; pile-up effects included (waveform treatment in progress); event building and PID algorithms (2016-2020);

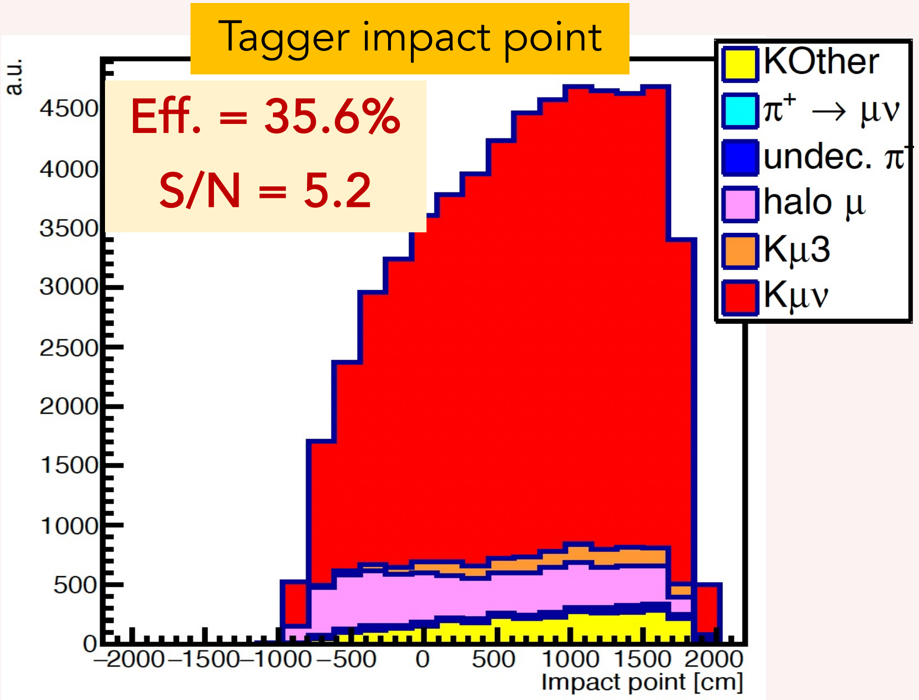
- Large angle positrons and muons from kaon decays reconstructed searching for patterns in energy depositions in tagger;
- Signal identification done using a Neural Network trained on a set of discriminating variables;

K_{e3} positrons -> constrain ν_e



Efficiency ~half geometrical

$K_{\mu 2}$ muons -> constrain ν_μ



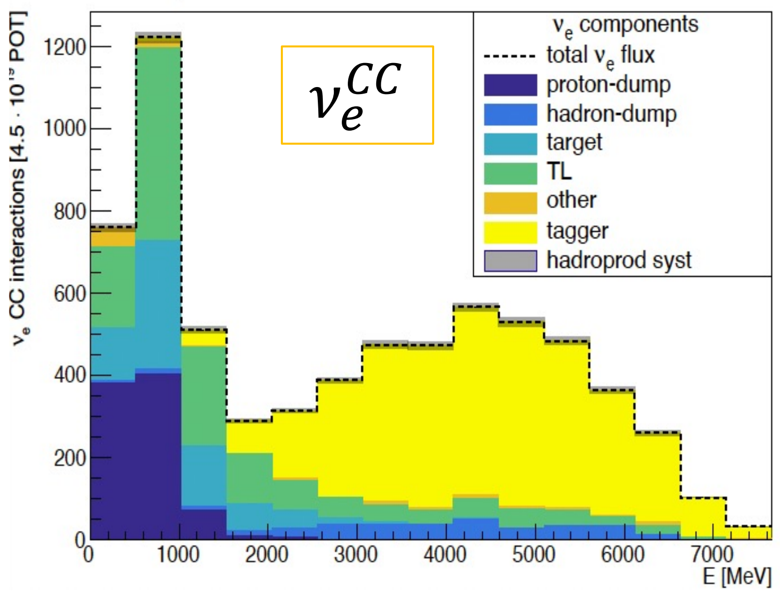
Efficiency ~half geometrical

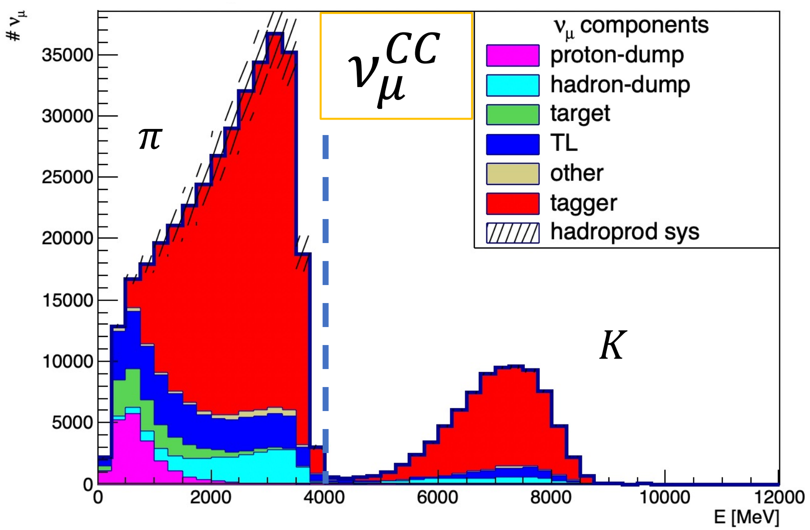
K_{e3} BR $\sim 5\%$ and K make $\sim 5-10\%$ of beam composition

ν-Flux: impact of hadro-production systematics

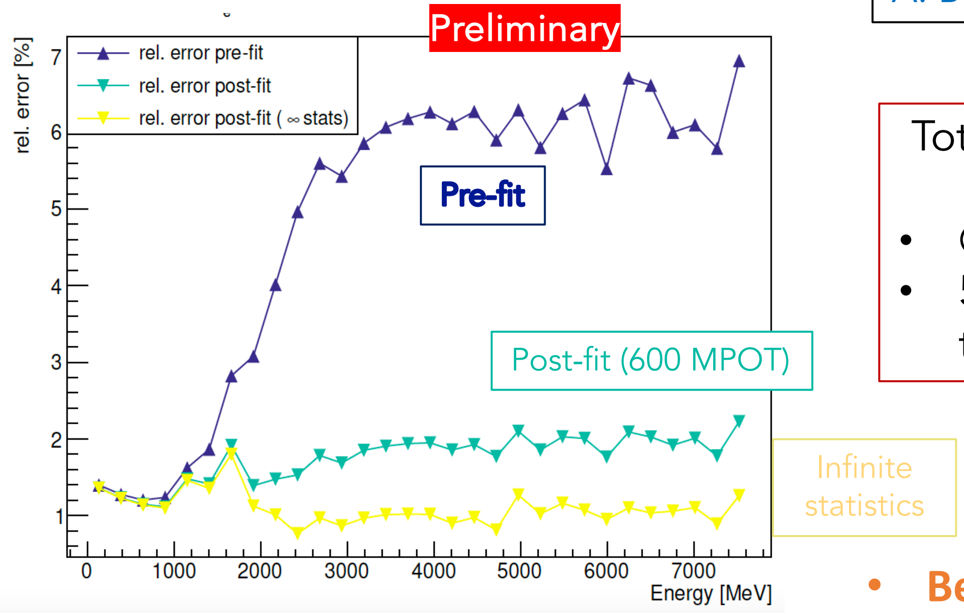
A. Branca et al., PoS NuFact2021 (2022) 030

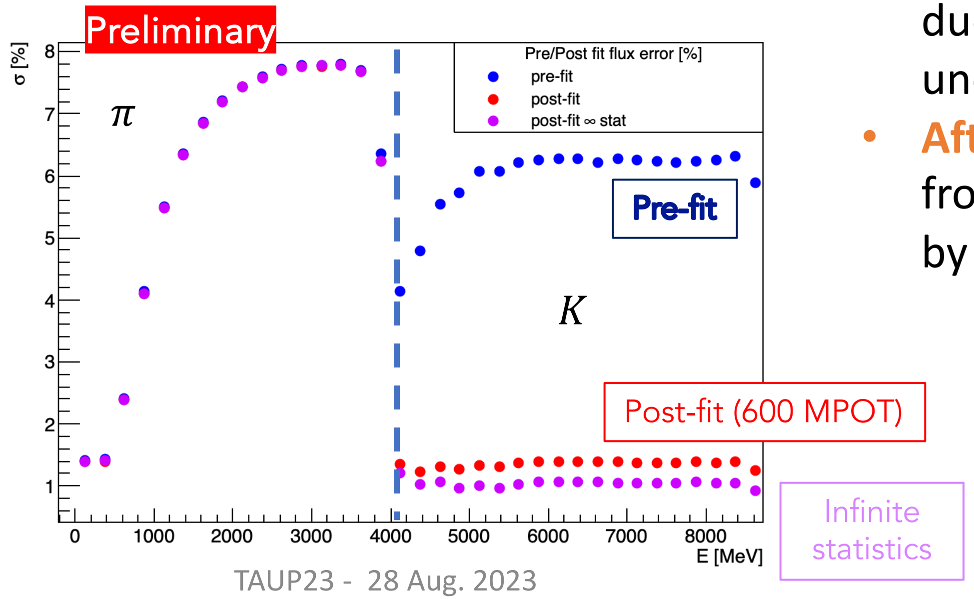
Neutrino interaction rates @ detector





Pre & Post fit relative errors on rates





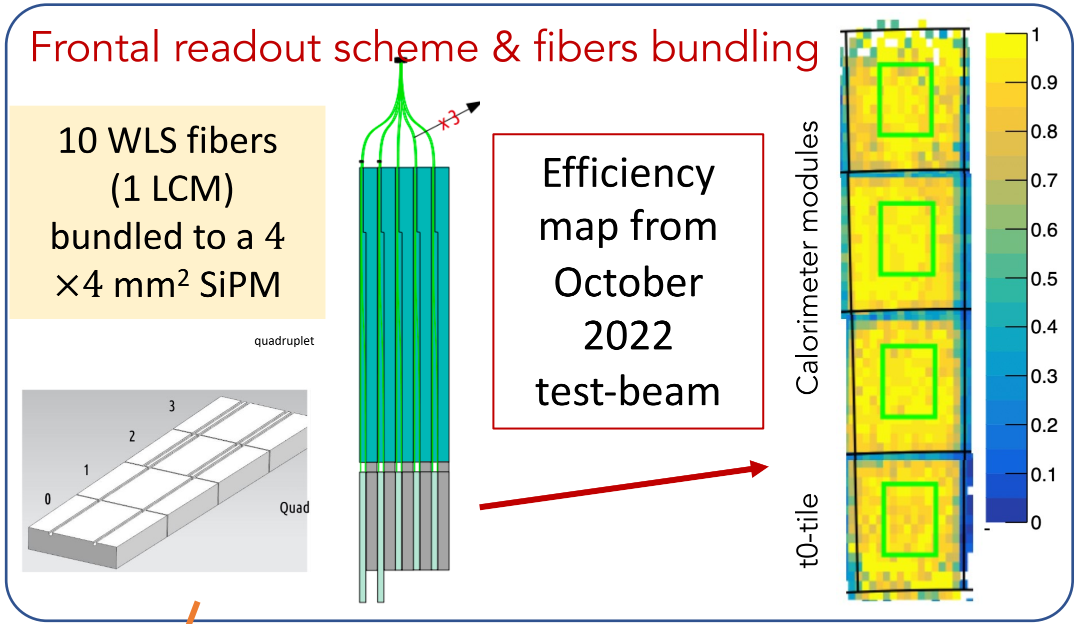
Total rates in 1 year of data taking

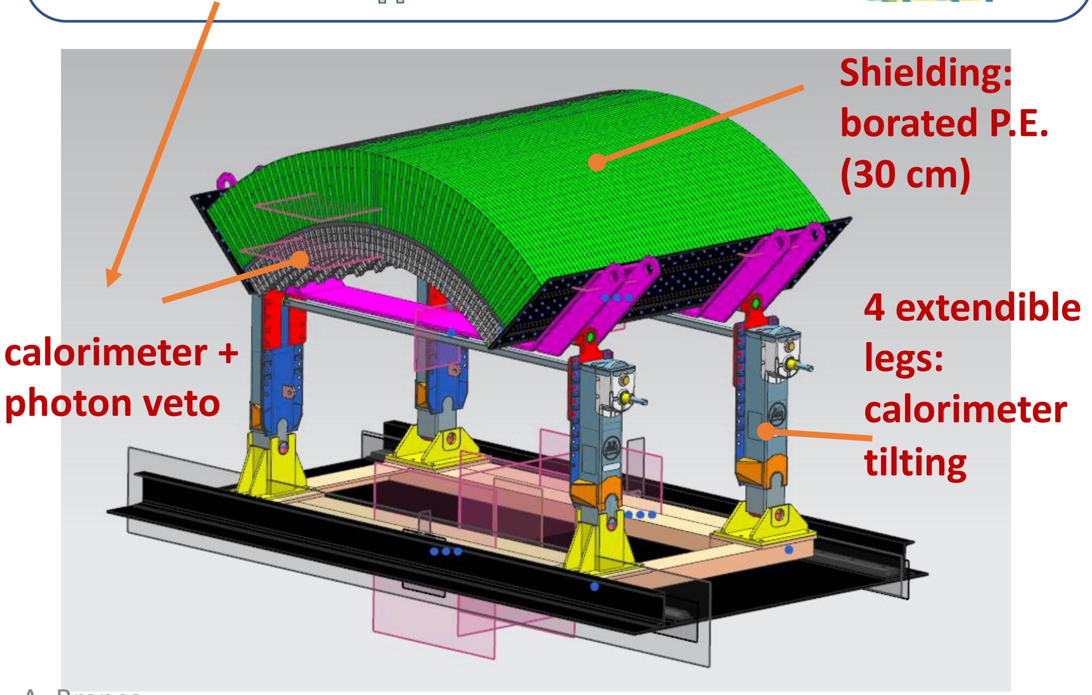
- @ SPS with $4.5 \cdot 10^{19}$ POT/year;
- 500 ton detector @ 50 m from tunnel end;

- **Before constraint**: 6% systematics due to hadro-production uncertainties;
- **After constraint**: 1% systematics from fit to lepton rates measured by tagger;

Achieved ENUBET goal of 1% systematics from monitoring lepton rates

The demonstrator

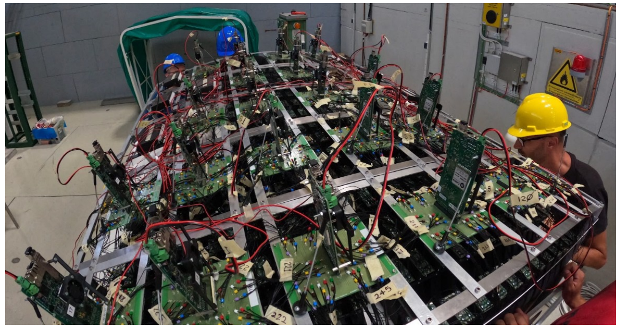




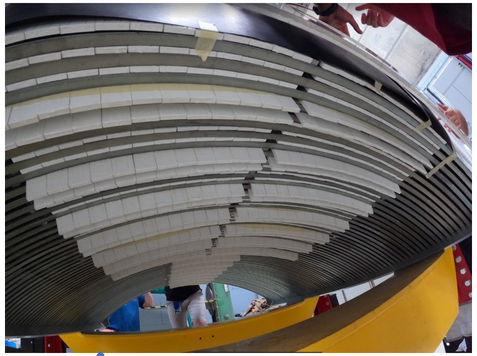
- Built a detector prototype to demonstrate:
  - Performance / scalability / cost-effectiveness;
    - 1.65 m longitudinal & 90° in azimuth;
    - 75 layers : iron (1.5 mm thick) + scintillator (7 mm thick) => (R,φ)=3X15 LCMs;
- central 45° part instrumented: rest is kept for mechanical considerations;
- modular design: can be extended to a full 2π object by joining 4 similar detectors (minimal dead regions);
- light readout scheme with frontal grooves:
  - driven by large scale scintillator manufacturing: safer production and more uniform light collection;
  - performed GEANT4 optical simulation validation;
- scintillators: produced by SCONIX and milled by local company;
- Test-beam October 2022: (R,φ,Z)=3X10x8 LCMs configuration, 400 channels in total;
- Test-beam August 2023: extended configuration, by adding (R,φ,Z)=3X25x7 LCMs, 1275 channels in total;

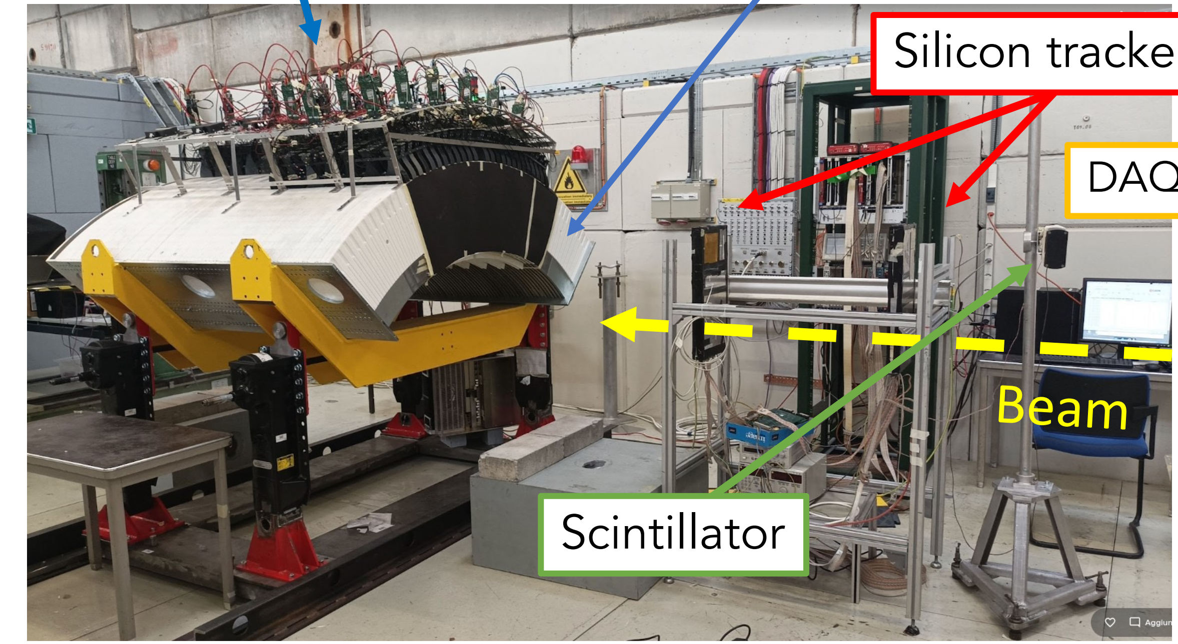
Preliminary results from 2022 test-beam

Front-end boards (SiPMs)
+ FERS (readout + HV)

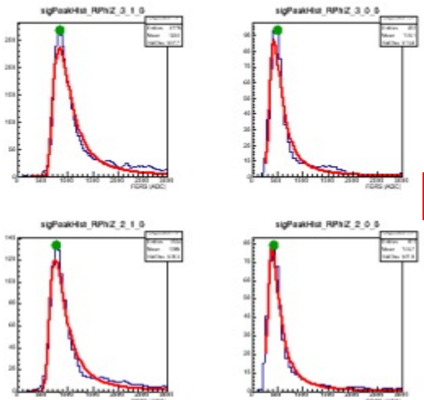


Demonstrator walls



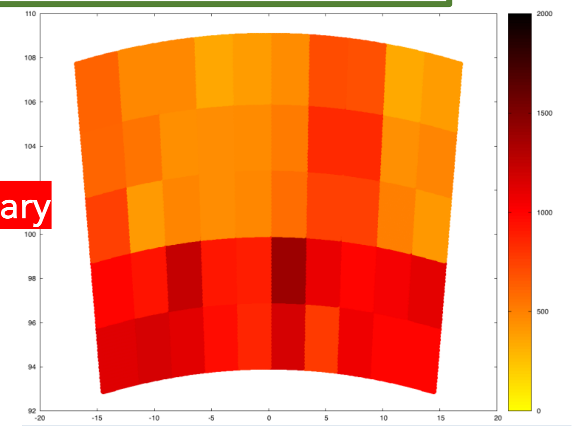


Calibration performed w/ m.i.p.s (π @ 5 GeV)



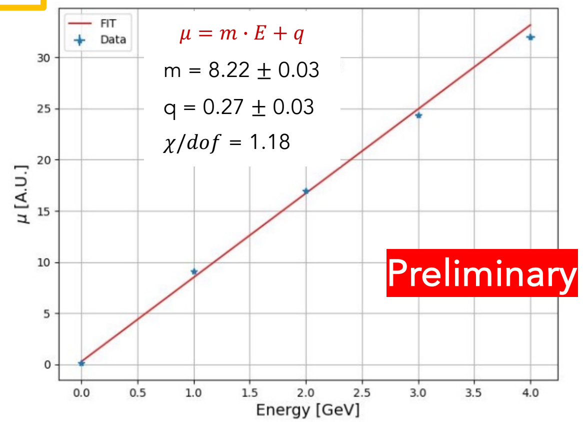
Preliminary

Example of m.i.p. distributions fit



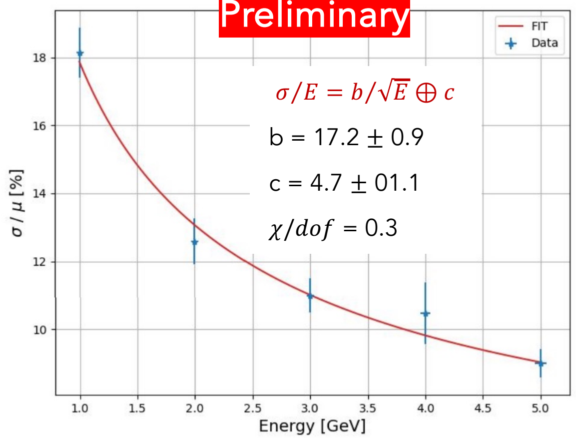
MPVs from m.i.p. fits
(fixed z layer of demo)

Equalizing difference in channel response O(20%) due to optical matching of fibers-tiles & fibers-SiPMs



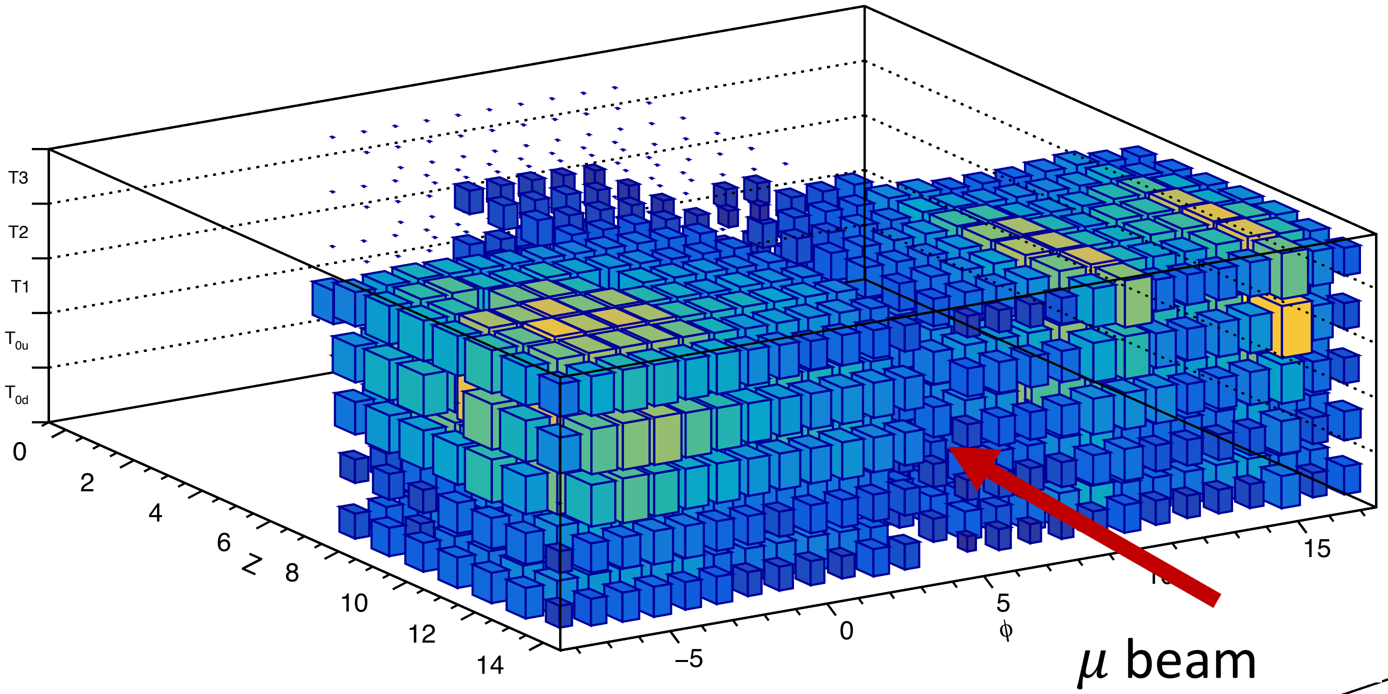
Preliminary

Preliminary



Performance goals achieved: good linearity & $\sigma/E = 18\%$ @ 1 GeV

A glimpse from 2023 test-beam

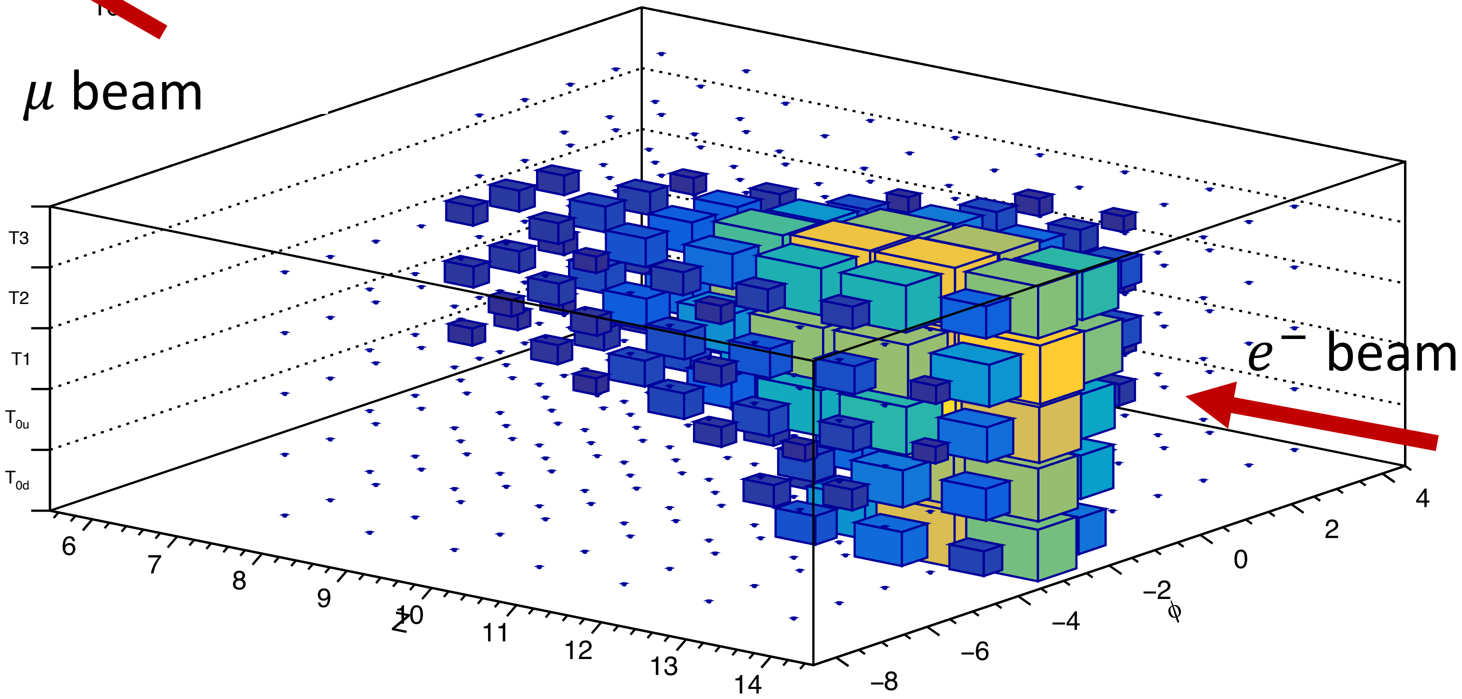


Calibration runs with 10 GeV muons

All channels have been covered by a large amount of statistics with mips -> will allow good equalization of channels

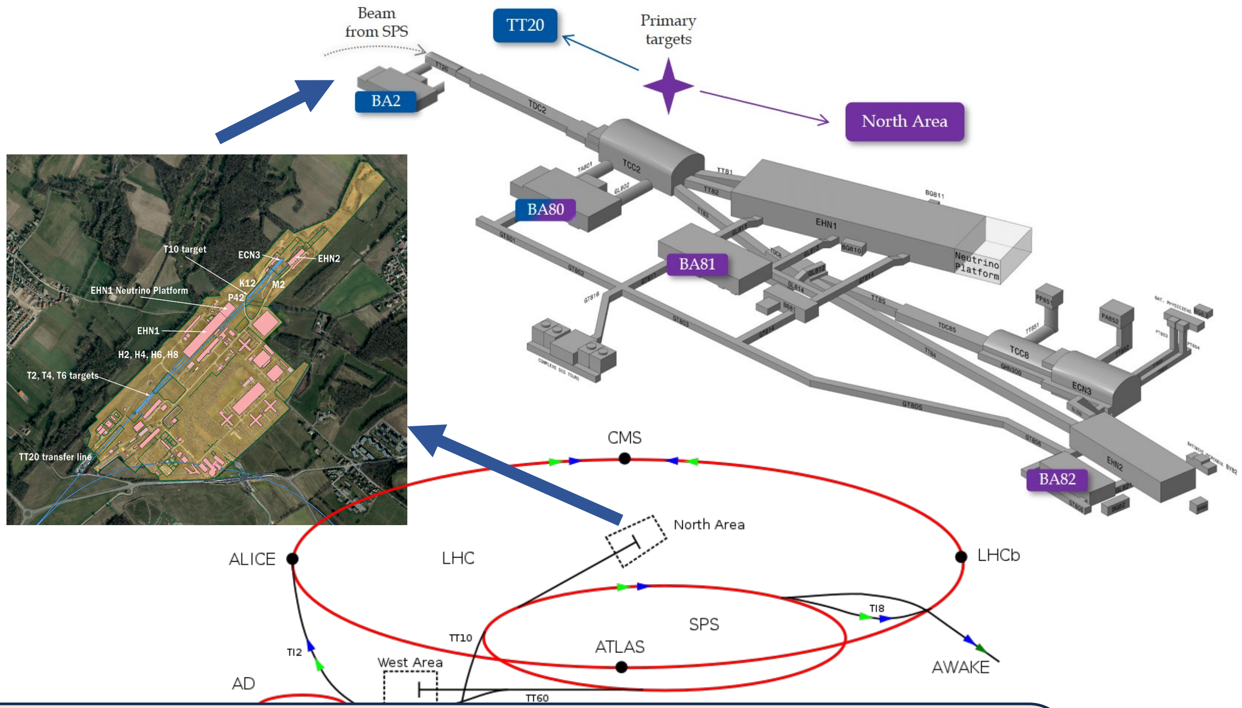
Energy scan with electron beams @ different energies for linearity and resultion studies

Example of shower profile from 5 GeV run



Plans for a real implementation @ CERN North-Area

- Exploit SPS and the ProtoDUNE detectors for a short baseline neutrino experiment:
  - Need to detail the physics program and detector requirement;
- Site dependent studies in the framework ok Physics Beyond Collider:
  - Accelerator, engeneering studies;
- Deliver a Conceptual Design Report in few years;
- Run after CERN LS3, during the DUNE Hyper-Kamiokande data-taking;



Options under consideration

- ➢ A dedicated neutrino beamline extracted from the North Area, pointing to ProtoDUNE (cheapest):
  - Maximize use of existing facility; ✔
  - Slow extraction easily implemented; ✔
  - Potential radiation issues; ❗
  - Interference w/ other experiments; ❗
- ➢ A dedicated extraction line near the North Area toward ProtoDUNE (cleanest):
  - No interference w/ experiments and existing facilities; ✔
  - Minor radiation issues; ✔
  - Higher cost; ❗
  - Potential issues w/ slow extraction; ❗

Summary & conclusions

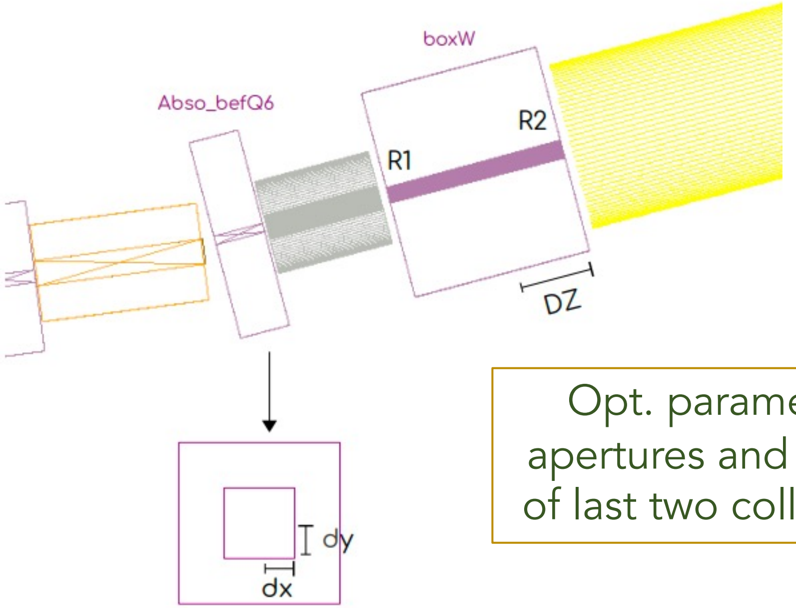
ENUBET will be the first monitored neutrino beam for neutrino cross-section measurements @ O(1%):

- Final design of beam transfer line allows to get 10^4 ν_e^{CC} events in ~2.3 years (@ SPS): paper on arXiv (arXiv:2308.09402 [hep-ex]) / submission to EPJC journal;
- Design of decay tunnel instrumentation finalized: demonstrator under test-beam @ CERN in October 2022 and August 2023;
- Detector simulation and PID studies done: achieved good identification of both positron and muon;
- Achieved 1% level in flux precision evaluating impact of hadroproduction systematic;
- Assessment of sub-leading systematics impact on neutrino flux due to detector effects;

Thank you for you attention!

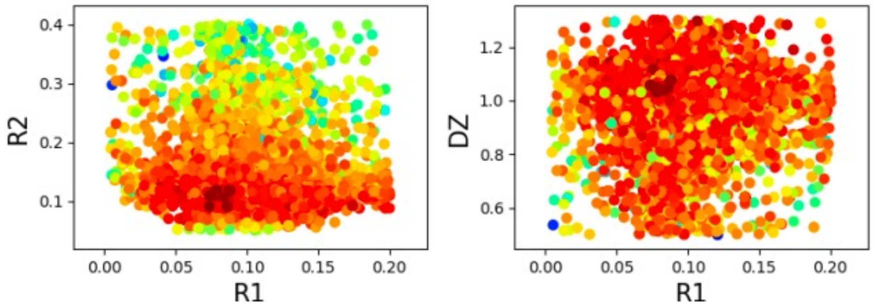
Backup

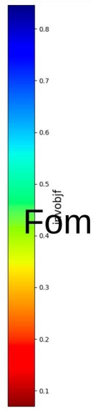
The ENUBET beamline: optimization studies



Opt. parameters: apertures and shapes of last two collimators

FOM dependence on opt. parameters





FOM = signal/background

Signal: π & K @ tagger enterance

Background: e^+& π hitting tunnel walls

Rates @ Tunnel entrance for 400 GeV POT	π^+ $[10^{-3}]$/POT	K^+ $[10^{-3}]$/POT
Design	4.13	0.34
Optimized	5.27	0.44

Background hitting tunnel walls	$e^+[10^{-3}]/K^+$	$\pi^+[10^{-3}]/K^+$
Design	7	59
Optimized	2	35

An optimization campain is ongoing:

- **Goal**: further improvement of the π/K flux at tunnel entrance while keeping background level low;
- **Strategy**: scan parameters space of beamline to maximize FOM;
- **Tools**: full facility implemented in Geant4 -> controll with external cards all parameters -> systematic optimization with developed framework based on genetic algorithm;

- About 28% gain in flux -> 2.4 years to collect 10^4 ν_e^{CC};
- Reduced backgrounds, but similar to signal shapes -> next step: improve FOM definition (include sgn/bkg distributions);

A next generation high precision ν-N cross section program

The ENUBET monitored neutrino beam allows:

High Precision Neutrino Flux ϕ:

- Absolute normalization and flavor content known at 1% level;
- High flux of electron neutrino, the appearing flavor at long-baseline exp for which less information are available;

A priori knowledge of Neutrino Energy E:

- At 10-25% level on an event by event basis;
- No need to rely on the reconstruction of the final state interactions;

Expected neutrino interaction rate at the detector:

A. Branca, G. Brunetti, A. Longhin, M. Martini, F. Pupilli, F. Terranova, Symmetry 2021, 13, 1625

$$N \sim \int \phi(E) \times \sigma(E) \times \mathcal{E}(E) dE$$

What detector technology do we need?

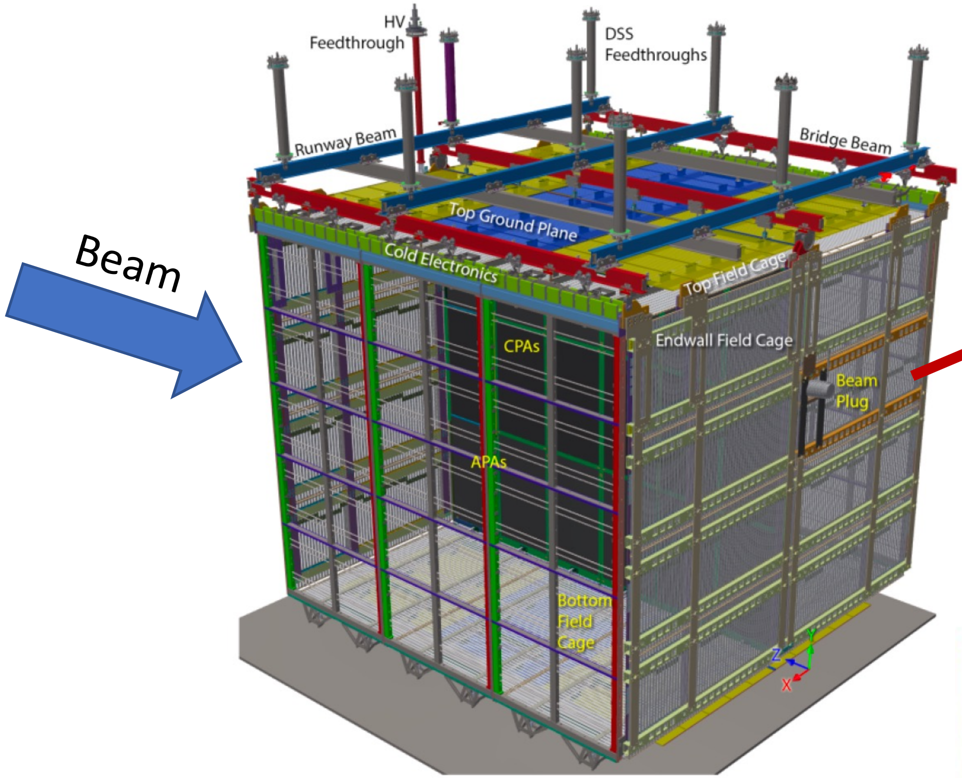
Auspicable a facility based on different detection techniques!

- Measure the $\sigma \times \mathcal{E}$ with same detector technologies used in long-baseline program;
- Disentangle interaction from detector effects using complementary techniques (high/low density and fine grained detectors);

Long-baseline program: ProtoDUNE (LAr TPC)

Measuring $\sigma \times \varepsilon$ for DUNE: exploit the ProtoDUNE-SP detector @ CERN

- Already installed and under test-beams @ CERN (goal: demonstrate DUNE FD detector technology);
- The large size allows almost full containement of neutrino interactions;

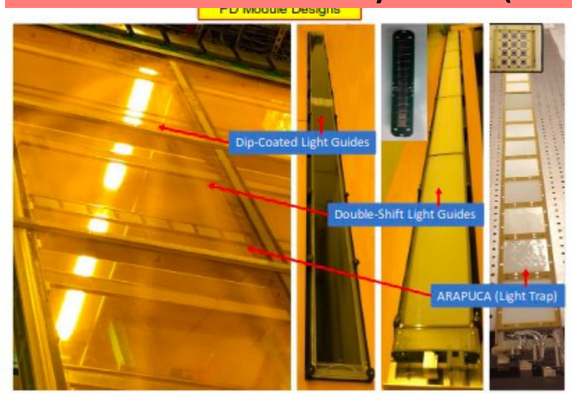


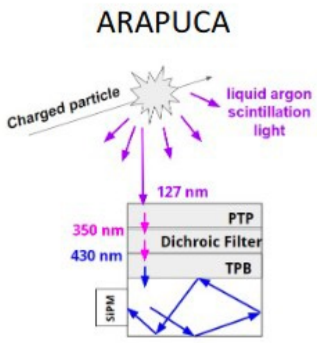
One of the two drift volumes

Dimensions:

- 7 m along beam direction;
- 7.2 m along drift direction;
- 6.1 m n height;
- Total mass about 400 tonnes;

PhotonDetection System (embeded in anode plane)



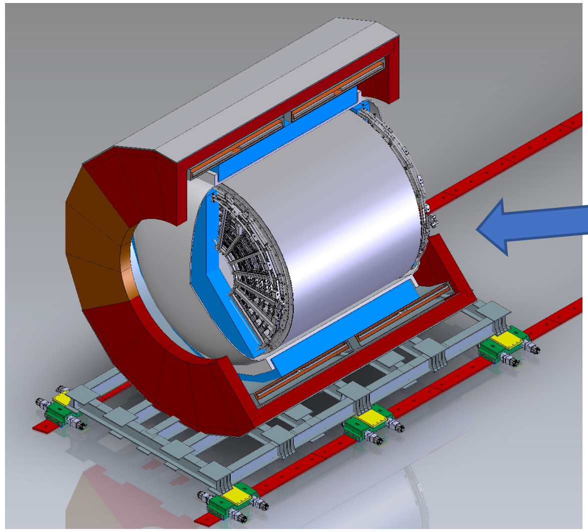


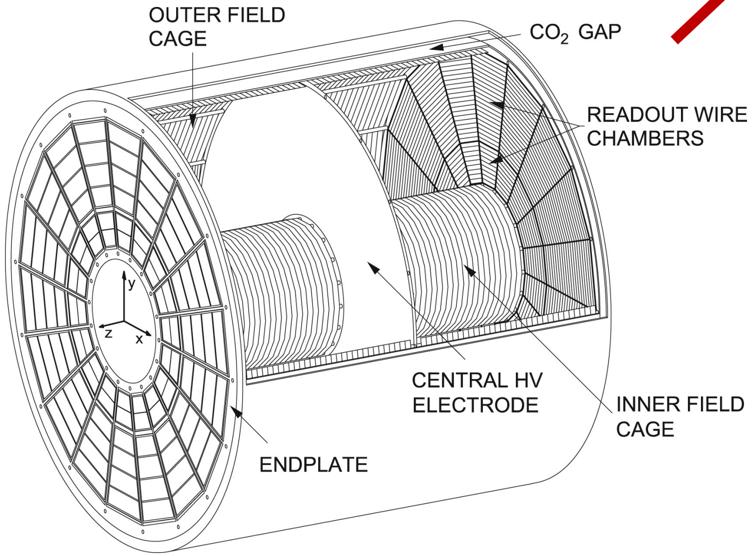
Decoupling interaction from detector Ɛ: LAr and GAr

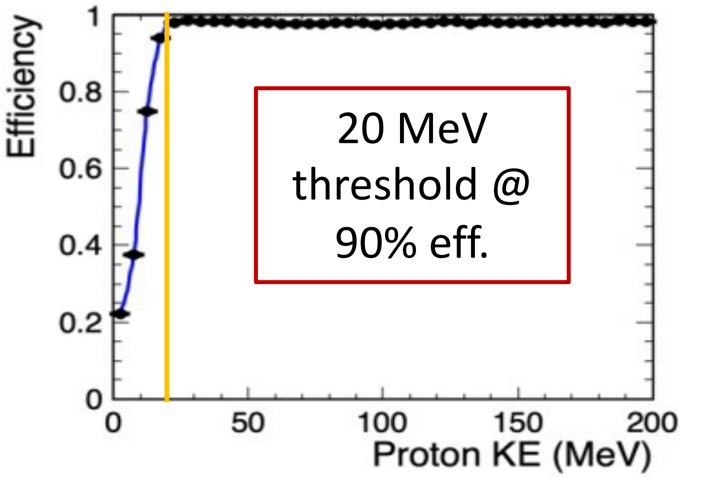
Ideal solution: exploit simulatneously liquid and gas TPC

- Gas phase TPC will be emploied in the ND-GAr at the DUNE ND complex;
- TPC based on the design of ALICE; but operated @ x10 bigger pressure -> enhance neutrino event rate;
- Advantages of high pressure gas w.r.t. Lar TPC:
  - High momentum resolution (use of magnetic field);
  - Improved particle ID (in particular p-pion separation);
  - Low energy treshold (allows full reconstruction of hadronic system in neutrino interaction);

- Active volume divided in two parts by central cathode;
- Radius of 2.6 m;
- Length of 5 m;
- Total mass of 1 tonne;





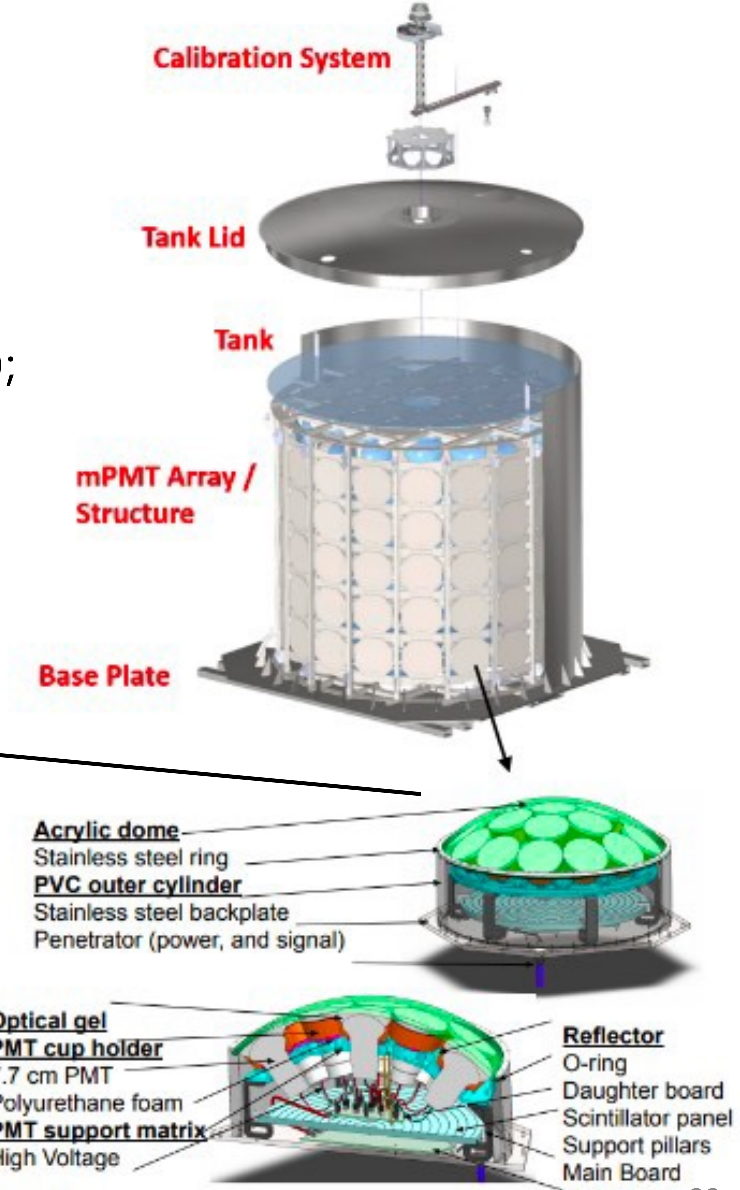


Long-baseline program: WCTE (water)

Measuring $\sigma \times \varepsilon$ for Hyper-K: the proposed WCTE could represent an interesting opportunity

- Start of detector assembly by November 2023 and start of operations in April 2024;
- Detector technology and event reconstruction smilar to that of Hyper-K FD -> reduction of systematics in cross sections and oscilation analyses;
- Fiducial mass is contained:
  - Can perform ν_μ^{CC} cross section measurements (ν_e^{CC} sample not significant);
  - Muon containement limited -> envisage a downstream spectrometer;

- Diameter of 3.8 m;
- Height of 3.5 m;
- Total mass about 40 tonnes;
- multi-PMT photon detectors, 19 PMT each, for Cherenkov light detection;

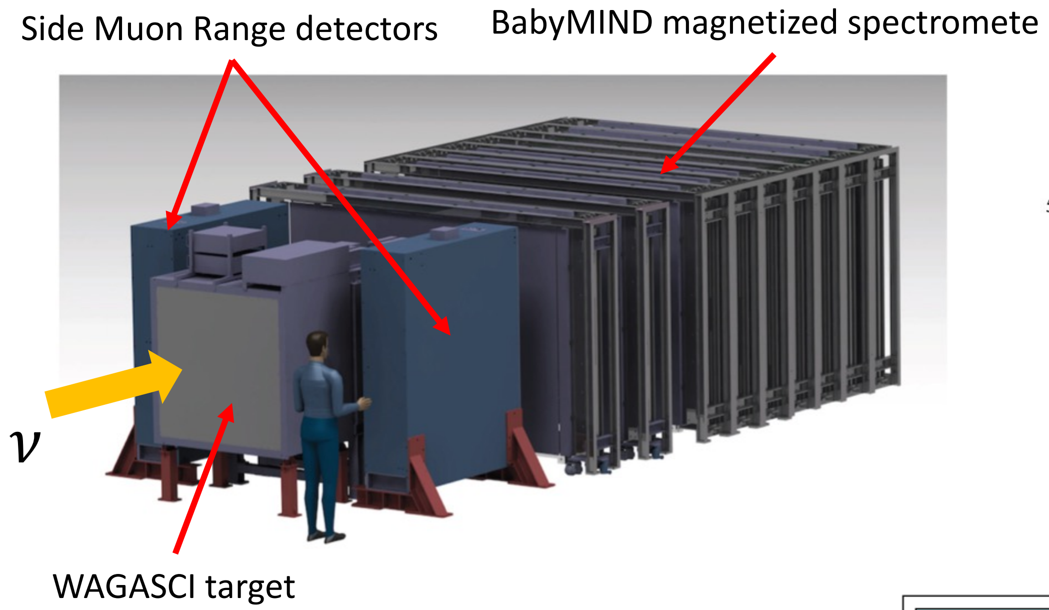


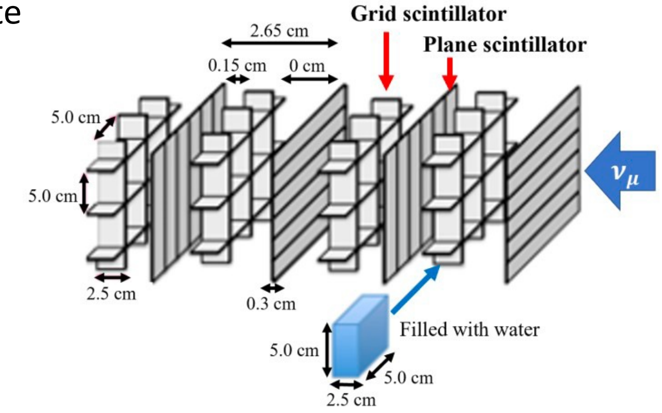
Decoupling interaction from detector ε: water Cherenkov

Ideal solution: use of fine-grained detectors with water target

WAGASCI:

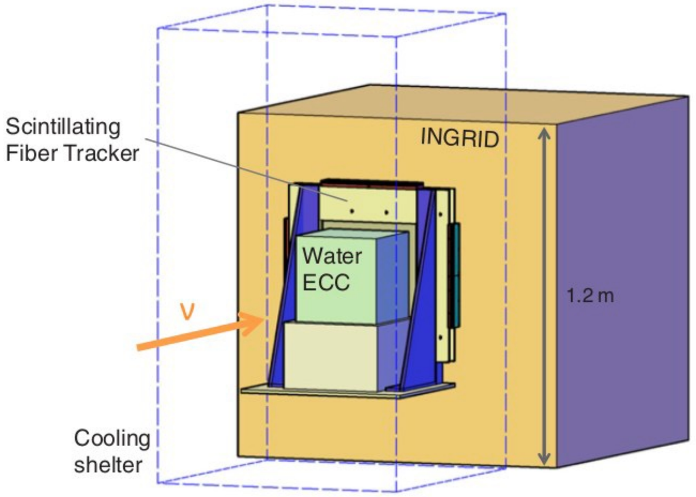
- 0.6 tonne water target;
- 3D grid-like structure of plastic scintillator enclosing cells of O(cm) linear size;
- Two mu side modules (steel plates and scintillator slabs);
- Downstream mu spectrometer (BayMIND);

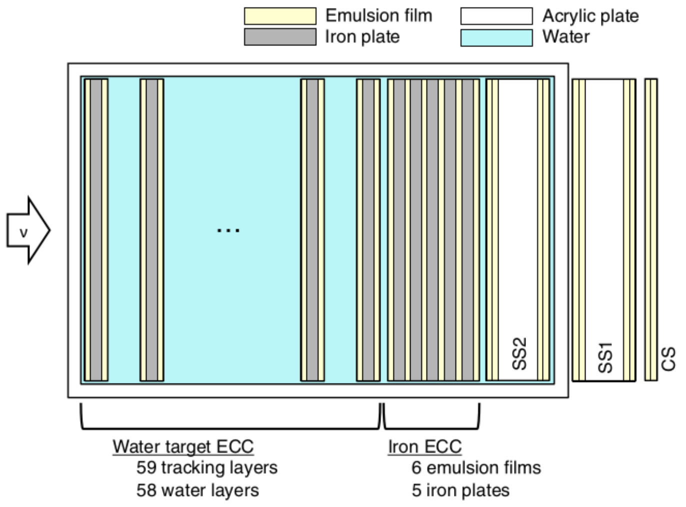




NINJA:

- Sandwitch structure: nuclear emulsion films and iron plates (500 μm thick) intervealed with water layers (2 mm thick);
- Downstream: tracker (scintillating fiber) -> match/timestamp of tracks in emulseion;
- One INGRID module -> muon range;





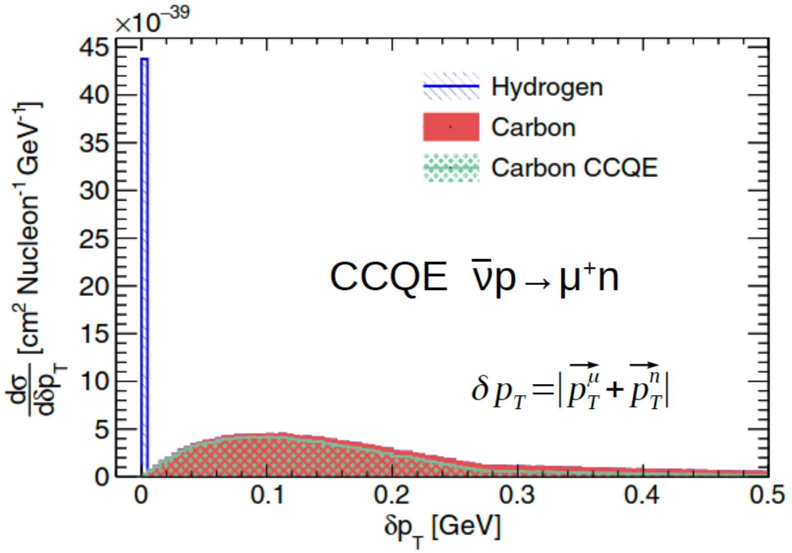
Thresholds: 200 MeV hadrons / 50 MeV protons & pions

Neutrino interactions with Hydrogen

Precision measurement of neutrino scattering off hydrogen and deuterium:

- Clean and solid base to build reliable models not affected by nuclear effects;
- Can be extrapolated to higher Z materials;
- Detailed studies on the nucleon structure exploiting a bare weak probe;

Indirect approach: exploit the transverse momentum imbalance due to nuclear effects have been proposed to disentangle hydrogen interactions from those to other nuclei in composite materiale (graphite targets);



Direct approach: using a liquid-hydrogen target, providing a fully unbiassed measurement

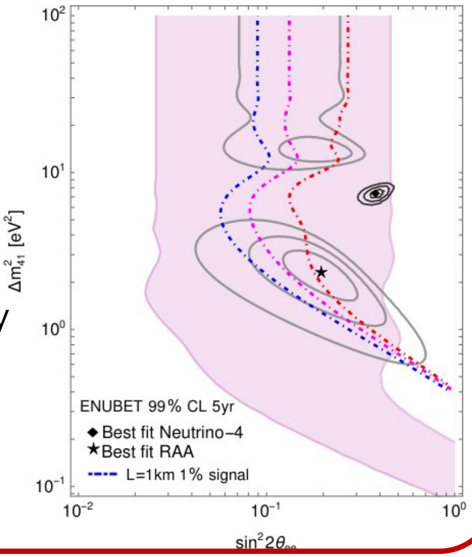
- ➢ Challenging due to safety requirements constraints for underground facilities;
- ➢ Proposal to use the magnetized bubble chamber technique with modern digital camera techniques;

ENUBET within Physics Beyond Collider framework

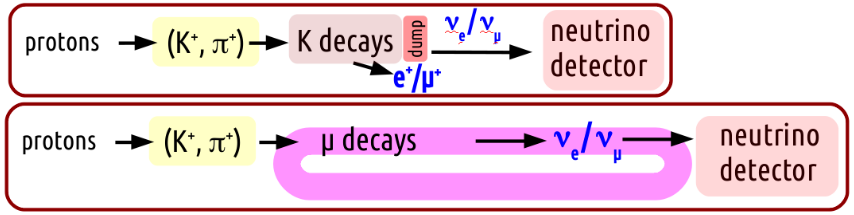
Accelerator and engeneering detailed studies, assessment of the facility costs, investigate posssibility to exploit ENUBET for cross section experiments at CERN North Area

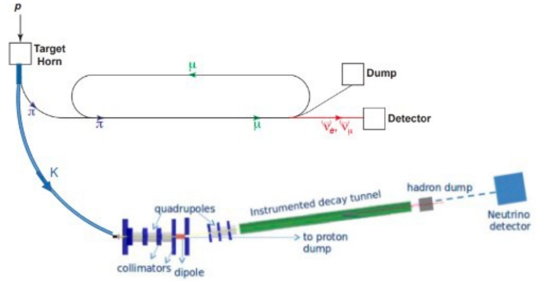
Assess Beyond Standard Model physics opportunities

Sterile neutrino: some results already available [L. Delgadillo, P. Huber, Phys. Rev. D 103, 035018 (2021)]



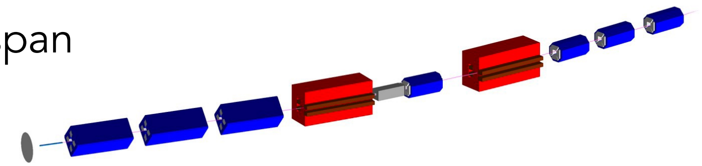
Assess synergy with nuSTORM. Common points: proton extraction line, target station, first stage of meson focusing, proton dump, neutrino detector





	Decay region	Hadron dump	Proton extraction, energy, focusing	Target, sec. transfer line, p-dump	Neutrino detector
ENUBET	~40 m. Instrumented.	Yes. Dumps μ in addition → preventing a (small) ν_e pollution to K_{e3} - ν_e	Slow extraction (+ quad triplets) "slow" in bursts (+horn) 400 GeV	similar	Similar but at ~100 m (some flexibility)
nuSTORM	Replaced by straight section of the ring (180 m).	No. μ kept: the most interesting flux parents.	Fast extraction (+horn) 100 GeV	similar	Similar but at > 300 m from target (ring straight section)

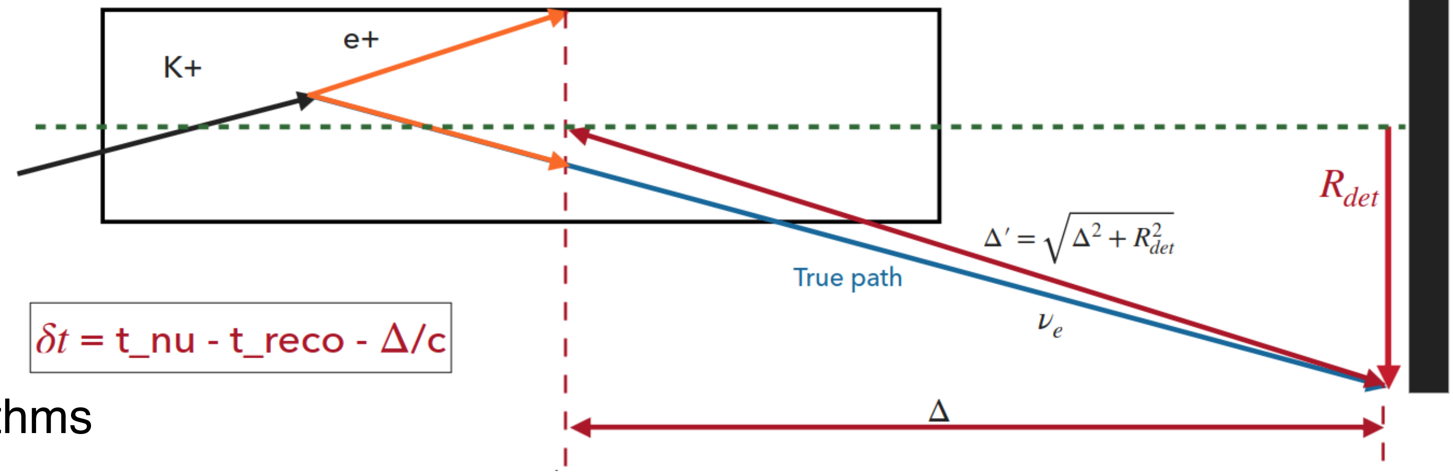
Multi-momentum beamline studies to span HyperK and DUNE region of interests



Time tagging

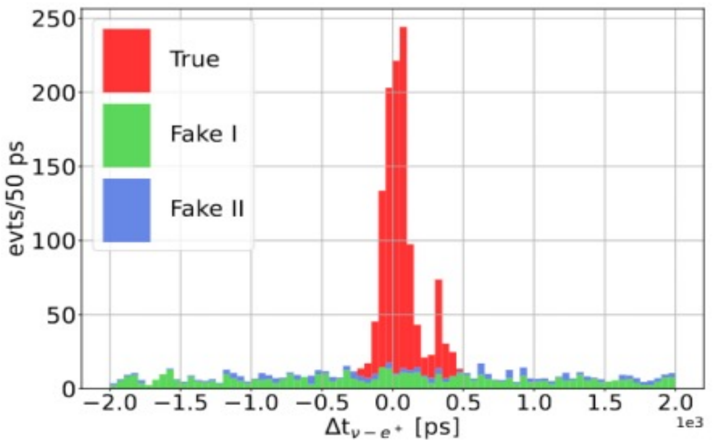
Investigating the possibility to operate ENUBET as a time-tagged neutrino beam

- Time coincidences of νe and e+;
- Flavour and energy determination enriched by charged lepton observation at decay level;

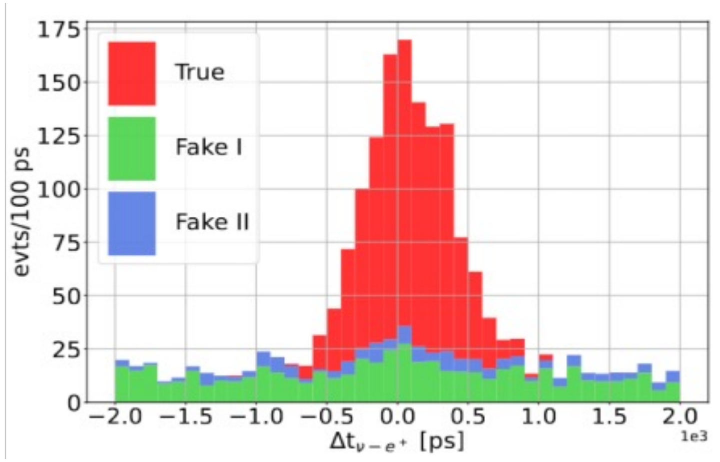


δt = t_nu - t_reco - Δ/c

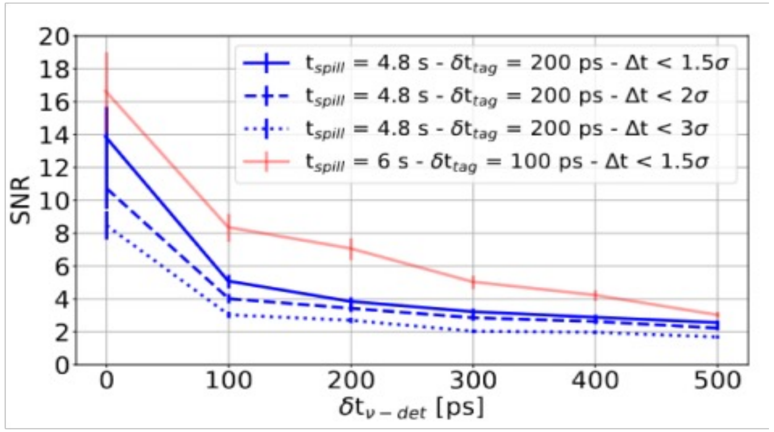
Employed full beamline simulation and PID algorithms



Infinite time-res. both for tagger and ν-det
Intrinsic 74 ps spread (1σ) due to the size of calorimeter modules (11 cm) and indetermination of the decay point



Smearing of the distribution assuming:
δttag=200 ps – δtdet=200 ps



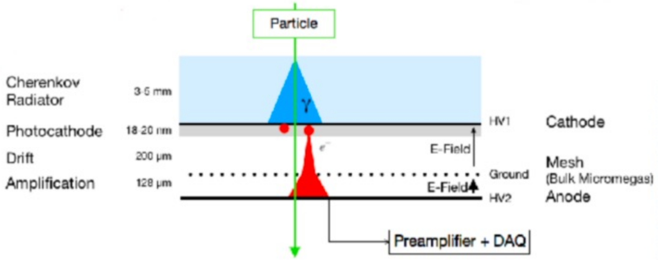
Eff = 75.6%
S/N = 3.8

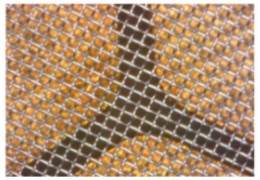
with δttag=200 ps – δtdet=200 ps

Lepton reconstruction and identification:

$\pi_{\mu 2}$ muon reconstruction to constrain low-energy ν_μ

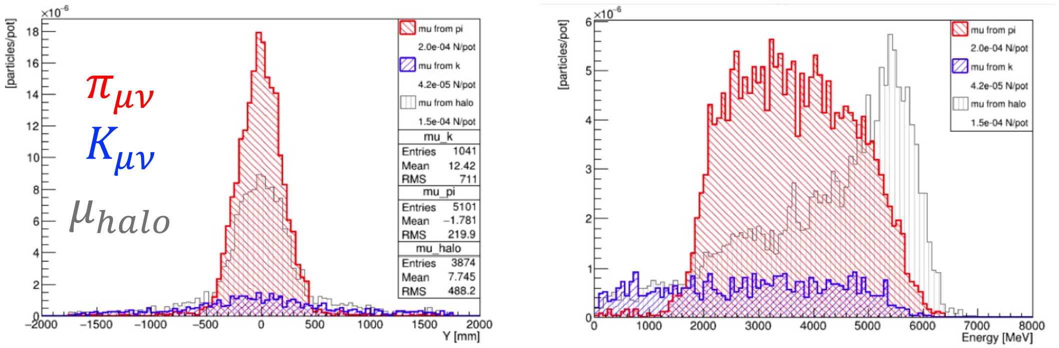
✓ **Low angle muons**: out of tagger acceptance, need muon stations after hadron dump

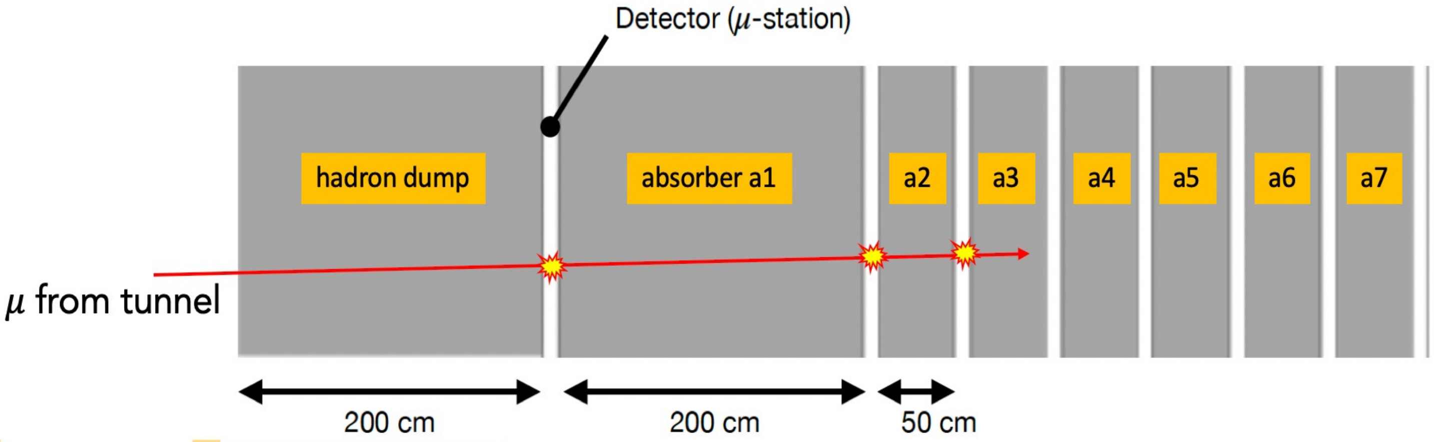


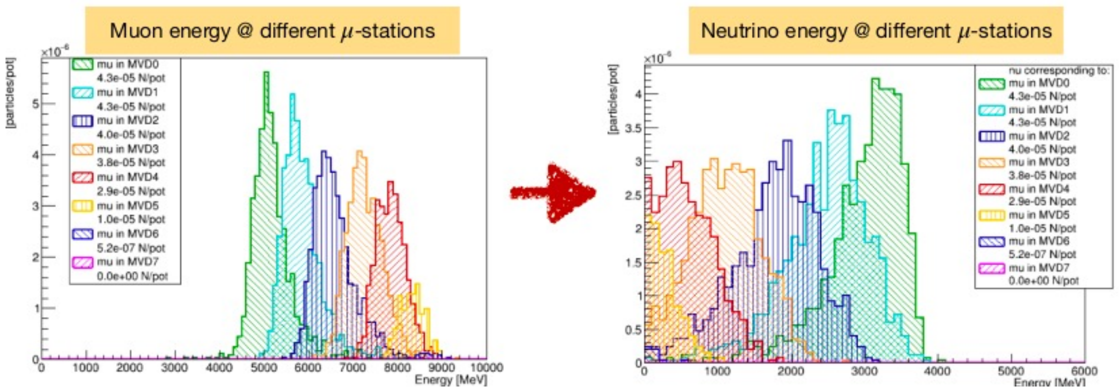


Possible candidates: fast Micromega detectors with Cherenkov radiators (PIMENT project)

Exploit differences in distributions to disentangle components







Hottest detector (upstream station): cope with ~2 MHz/cm^2 muon rate and ~10^{12} 1 MeV-n$_{eq}$/cm^2

Exploit:

- correlation between number of traversed stations (muon energy from range-out) and neutrino energy;
- difference in distribution to disentangle signal from halo-muons;

Detector technology: constrained by muon and neutron rates;

Systematics: punch through, non uniformity, efficiency, halo-μ;

Waveform simulation & pile-up

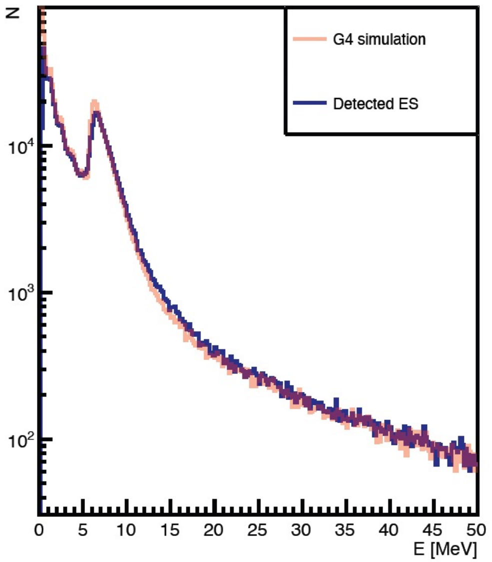
Implementation of waveform generation in the full simulation: as in real data (digitally sampled signals @ 500 MS/s) -> real pile-up treatment

- GEANT4 hit-level energy deposits are converted into photons hitting SiPMs (~15 phe/MeV, from test-beams & cosmic rays measurements);
- SiPM response simulated using GoSiP software: fine control on all sensor parameters;
- waveforms are processed with a pulse-detection algorithm: time and energy information are evaluated;
- results is used as input for event building;

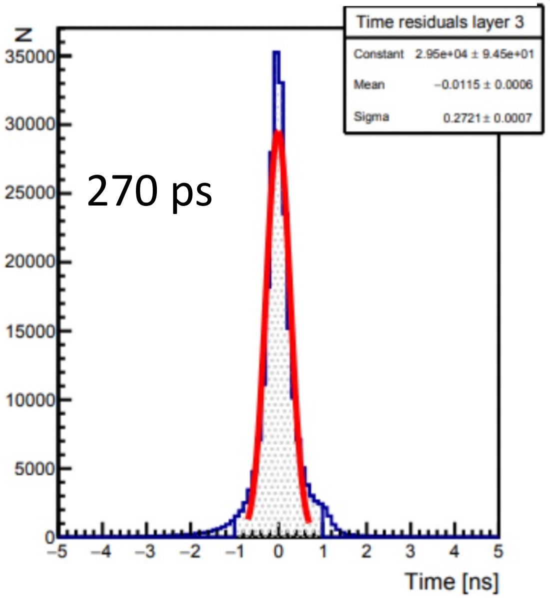
Complete assessment of pile-up effects on detector performance

pulse-detection algorithm optimized for faithful energy evaluation, high efficiency, and accurate time resolution

Geant4 energy/WF reco energy



Residuals: G4 true-time/WF reco



Transfer line and extraction scheme	Hit rate per LCM	detection efficiency
TLR5 slow	1.1 MHz	97.4%
TLR5 fast	10.4 MHz	89.7%
TLR6 slow	2.2 MHz	95.3%

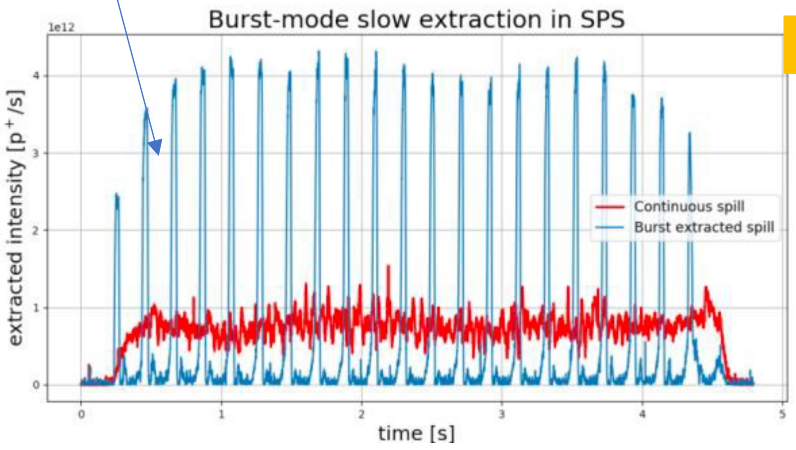
Slow extraction = 4.5×10^{13} POT in 2 s;
Fast extraction (horn) = $10\times$ slow extraction;

Horn based focusing

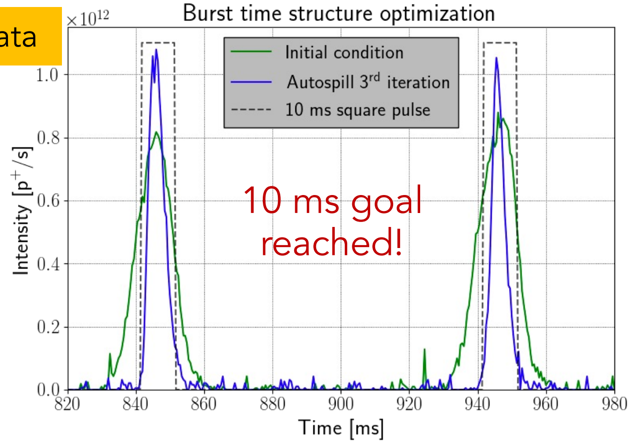
M.Pari et al., Phys. Rev. Accel. Beams 24, 083501 (2021)

Boosting the neutrino flux ➔ Employ magnetic Horn ➔ ⚠ Overkilling pile-up @ tunnel

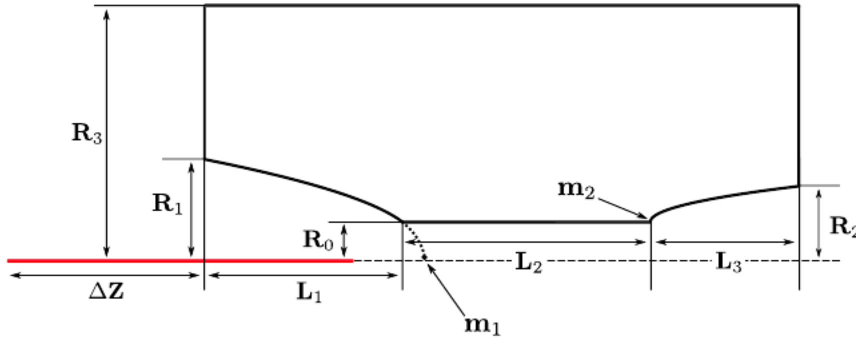
Burst mode slow extraction: multiple ms-long pulses slow-extracted during flat-top ➔ compatible with Horn and pile-up @ tunnel



from real data



New double parabolic geometry implemented



Dedicated tests at CERN-SPS:

- successfully implemented;
- optimized down to 10 ms length @ 10 Hz;

From simulation studies:

- 3 to 10 ms pulse length can be reached;

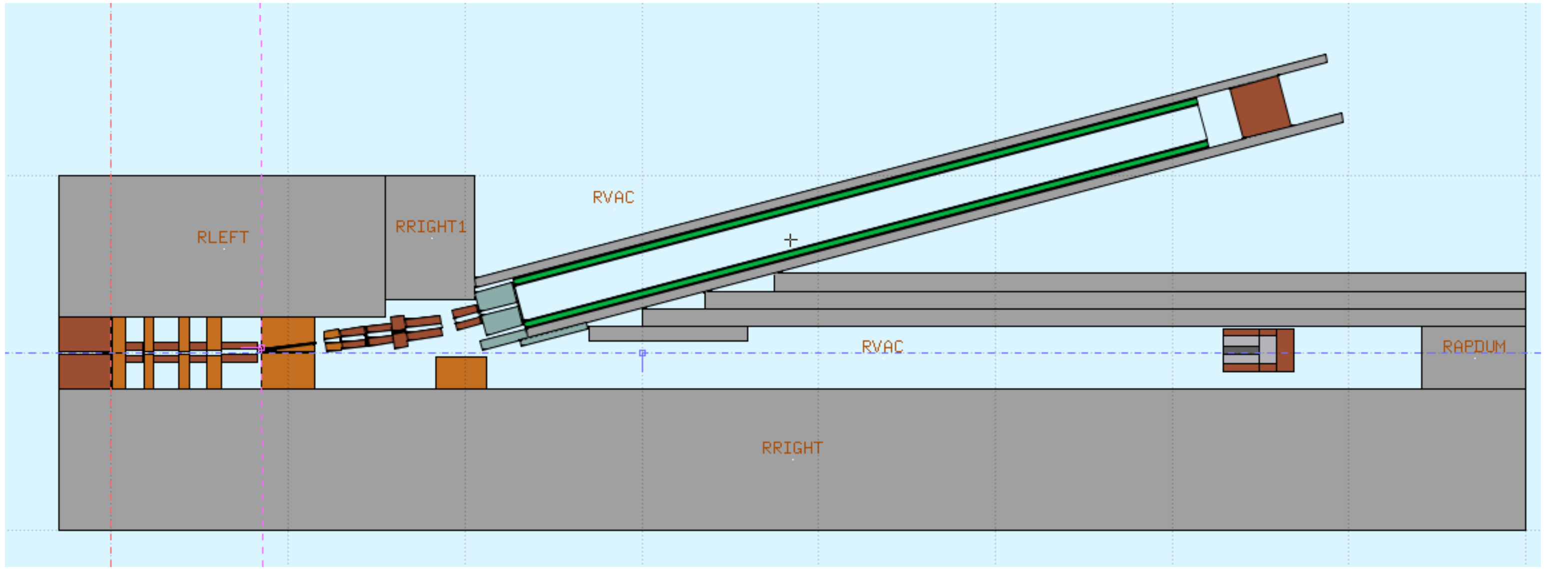
Horn optimization: search for best shape & current values to maximize flux

- developed a dedicated optimization algorithm based on Genetic Algorithm;
- tests show that a FOM* 3x static beamline can be achieved;
- NEXT: further studies on dedicated beamline fine-tuned for horn;

*FOM = # of K^+ within momentum bite focused at first quadrupole after the horn => beamline independent

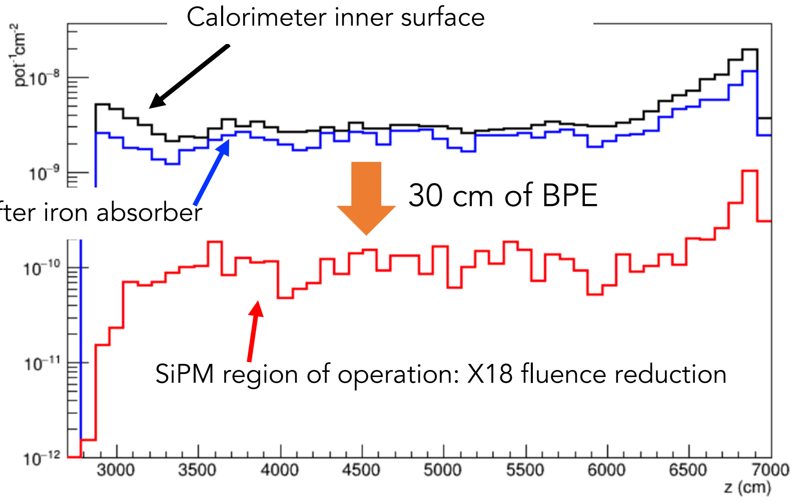
FLUKA irradiation studies

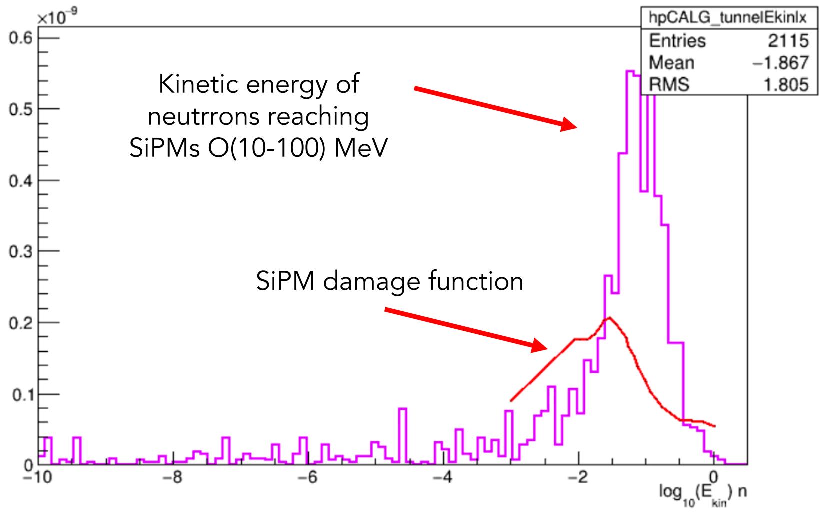
A detailed FLUKA simulation of the setup has been implemented (includes proper shielding around the magnetic elements)



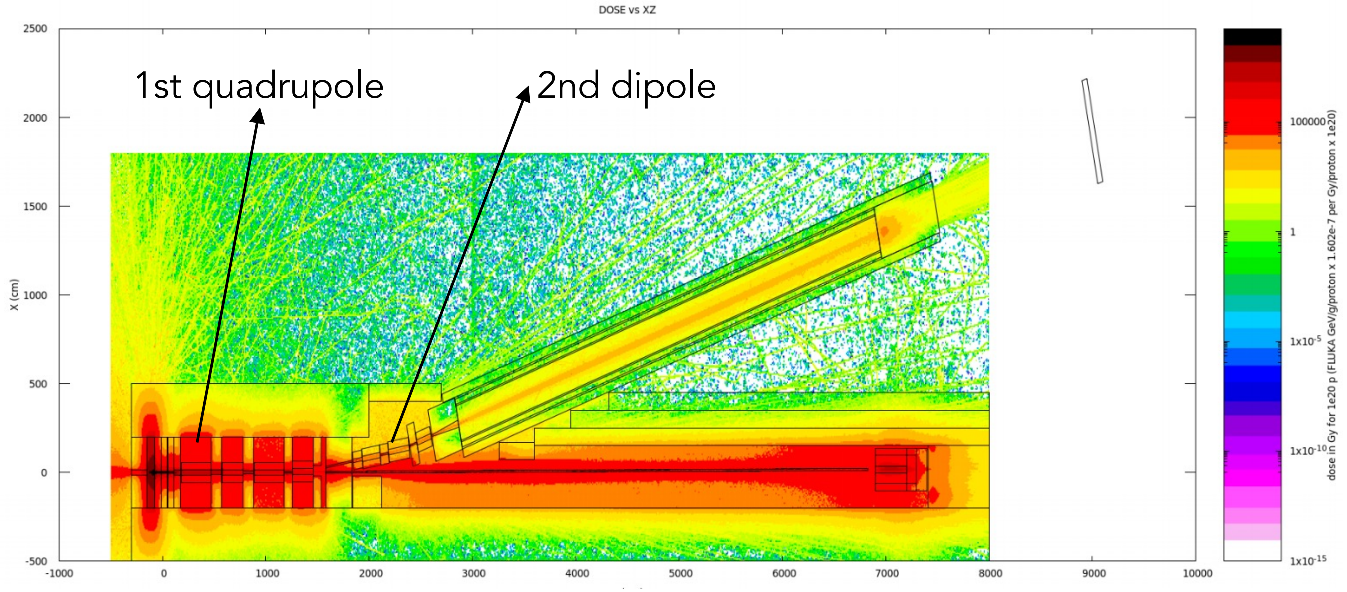
Neutron fluence provided by FLUKA guided the design of the detector tecnology for tagger:

-> SiPMs outside of the calorimeter





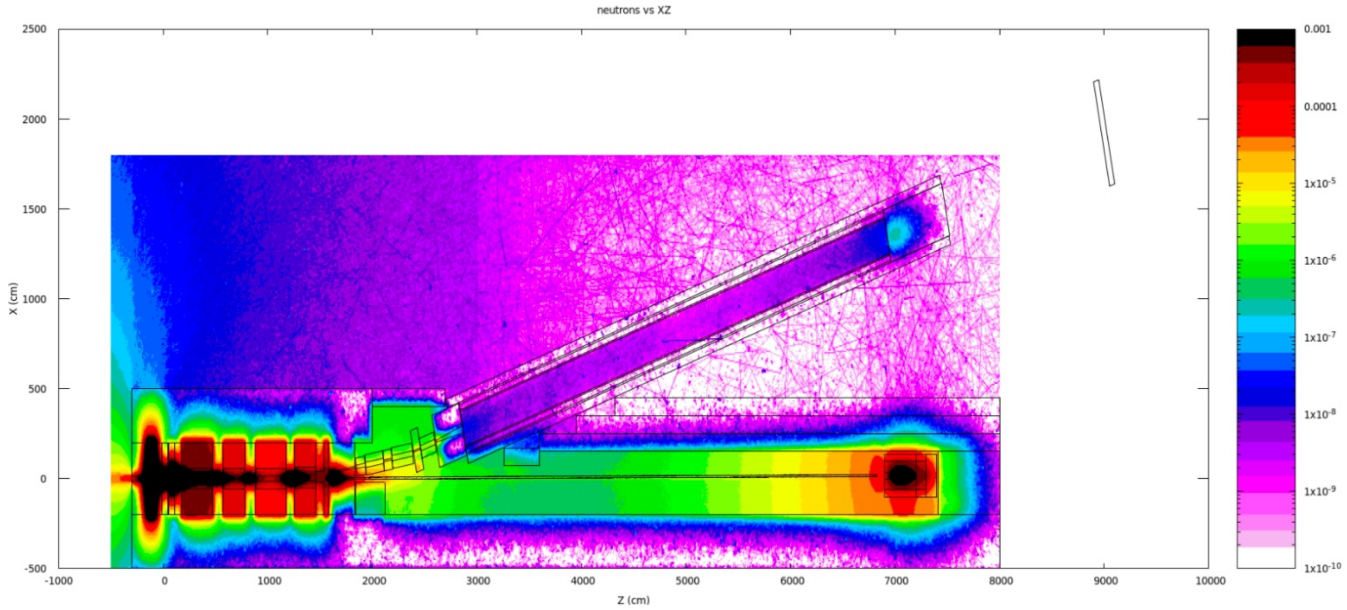
FLUKA irradiation studies



Dose for 10^{20} POT [Gy]

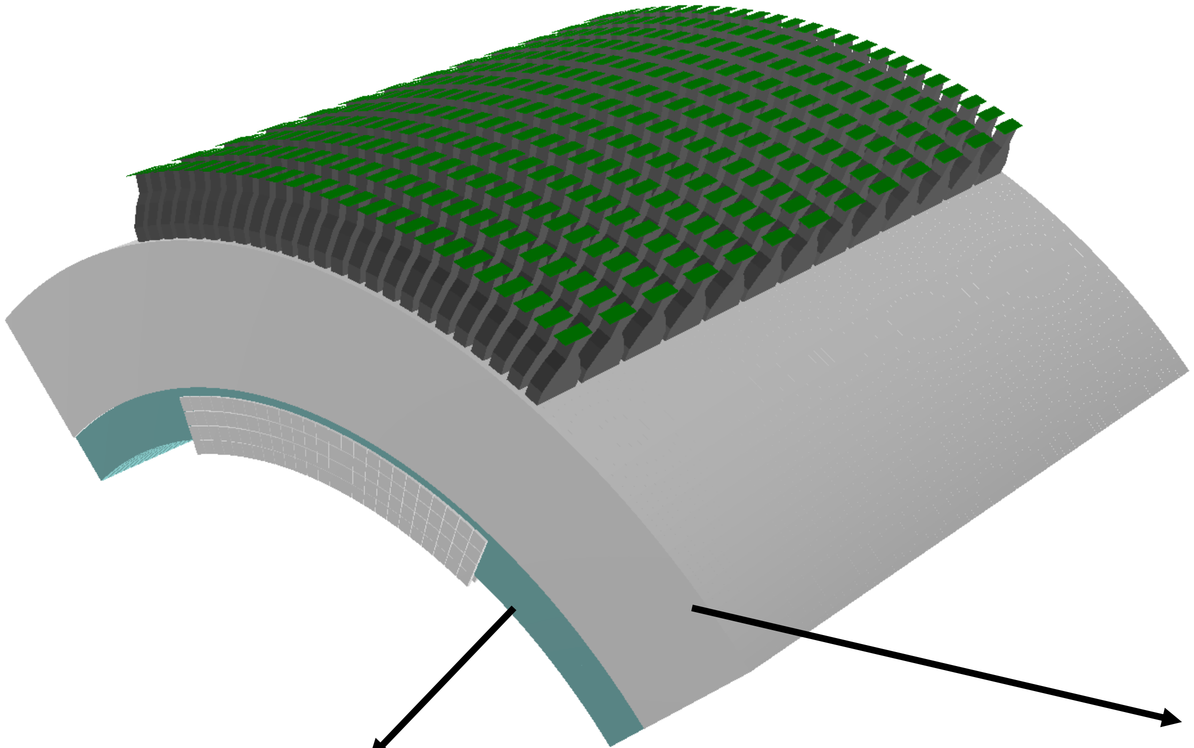
Hottest point -> quadrupole closest to target O(100-300 kGy): acceptable value for operations

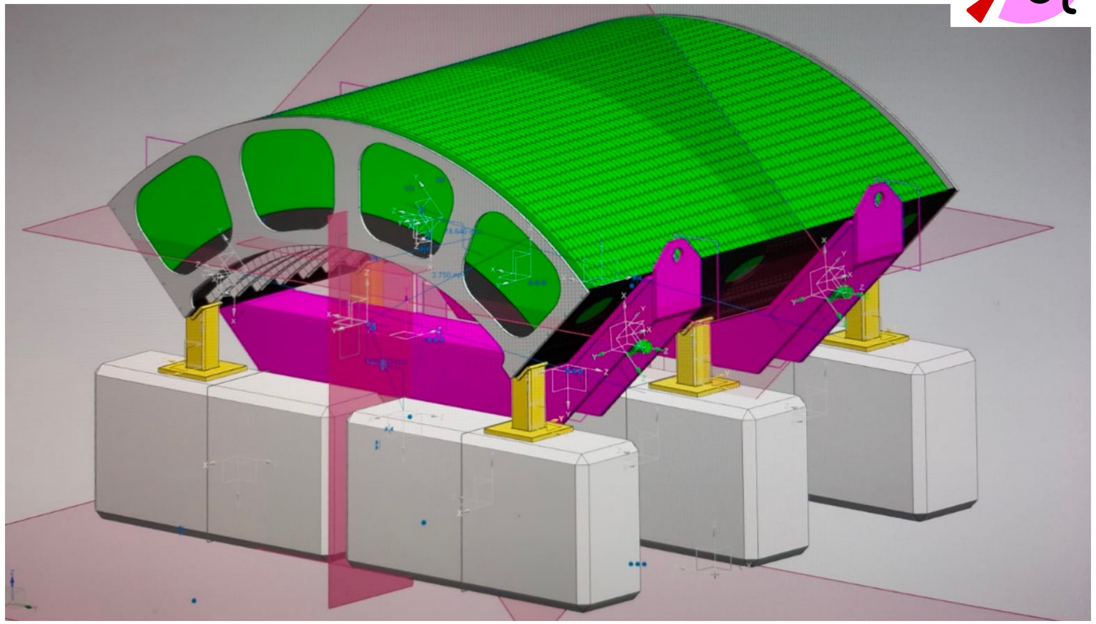
Neutrons/cm^2 for 10^{20} POT



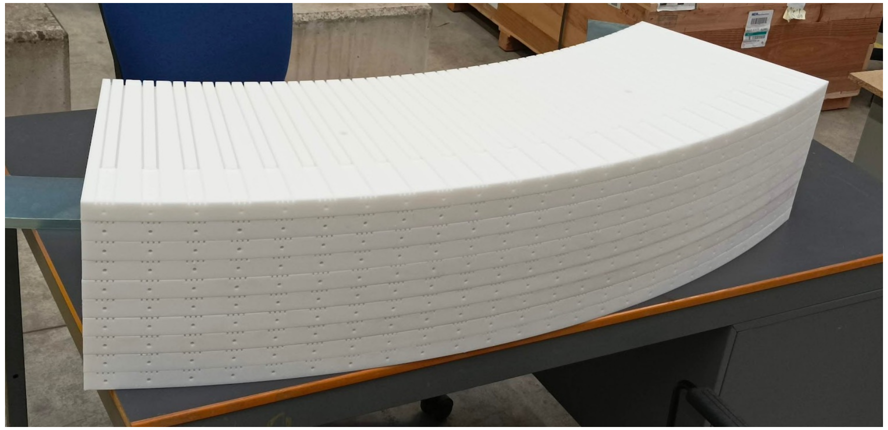
Demonstrator

Weight ~7 t



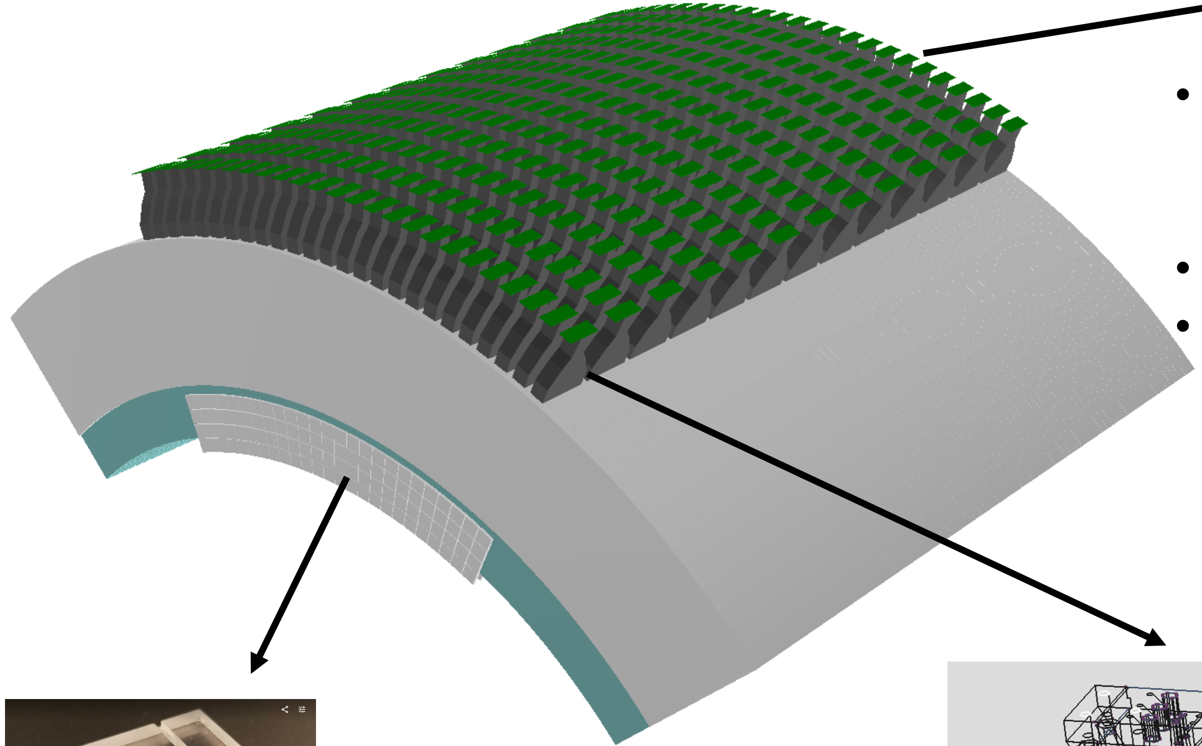


Machined iron for calorimeter absorber layers

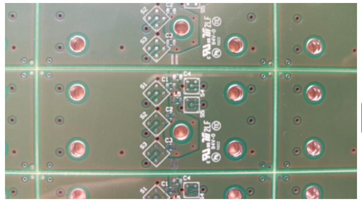


5% Borated Polyethylen arcs

Demonstrator

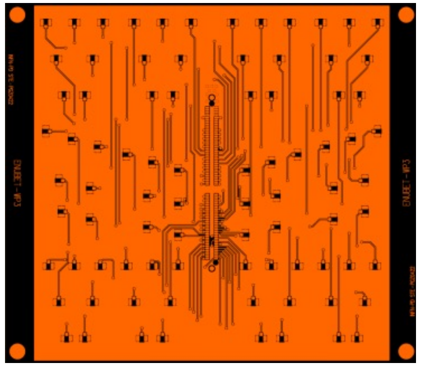


- ~1800 channels / 1275 instrumented;
- SiPM Hamamatsu;
- Hybrid readout (custom+commercial digitizers)

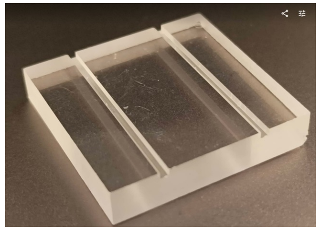


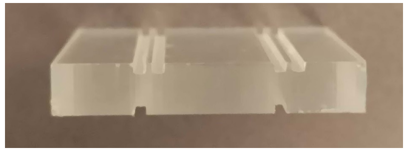
Front-end boards (SiPMs + HV)

Commercial read-out boards (CAEN A5202)

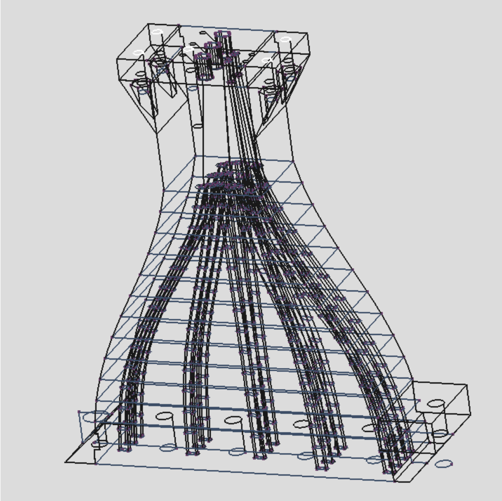


Custom interface board to connect 12 FEBs (60 chs) to 1 A5202





- 4335 scintillator tiles in different shapes;



- 3D printed fiber routers;
- Produced w/ 5 3D printers

The demonstrator

Construction @ LNL-INFN Labs

- 15 mins lift test with additional 2 tonnes (total 5.2 tonnes)

Iron arcs and borated polyethylen shielding

Lifting test of demonstrator

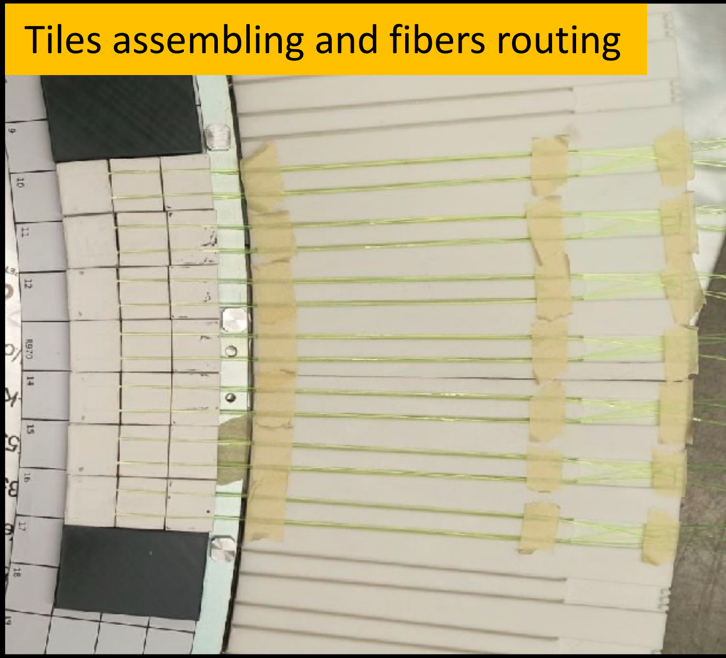
Fiber concentrator (boundling/routing to SiPMs)

The demonstrator

Construction @ LNL-INFN Labs

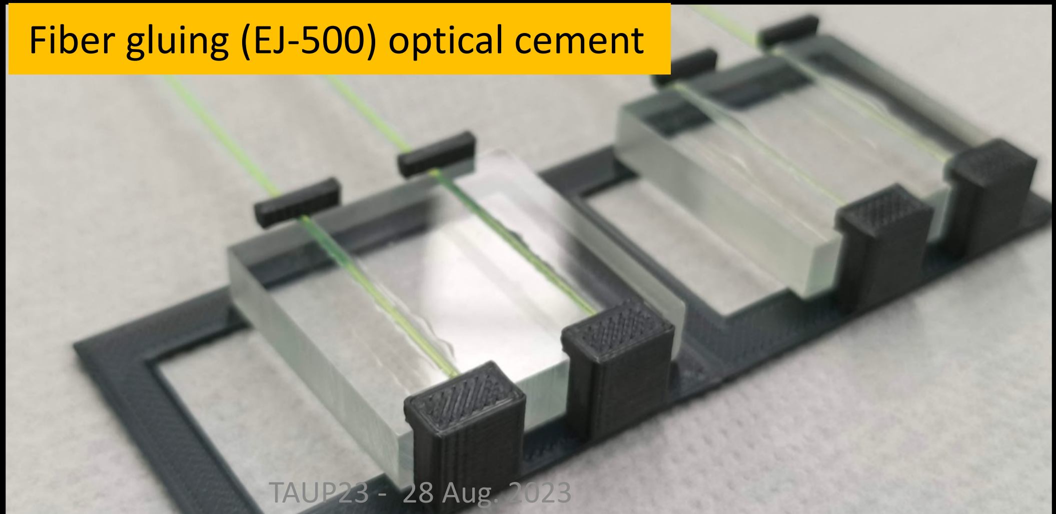
- The scintillator tiles

EJ-204 scintillator tiles – grooves for WLS fibers



Tiles assembling and fibers routing

Tile painting (EJ-510 / TiO_2 painting)

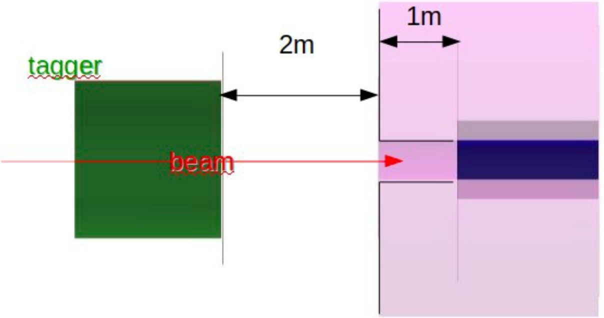


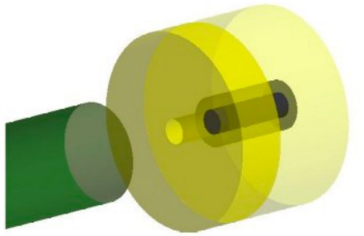
Fiber gluing (EJ-500) optical cement

Dumps

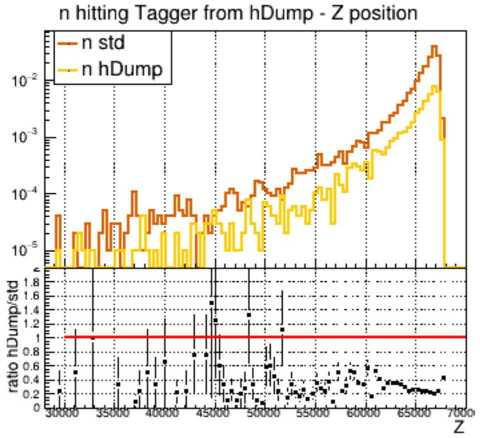
Hadron dump:

graphite core (50 cm diameter), inside layer of iron (1 m diameter), covered by borated concrete (4 m diameter) + 1 m of borated concrete placed in front of hadron-dump with opening for beam;





- ➢ design optimized to reduce the backscattering;
- reduction of the flux all along the tagger;
- in the last part of the tunnel, where neutron fluence is higher, ratio w.r.t. standard dump is ~0.2;



Proton dump:

similar structure, 3 cylindrical layers: 3 m long graphite core, surrounded by aluminum, covered by iron;

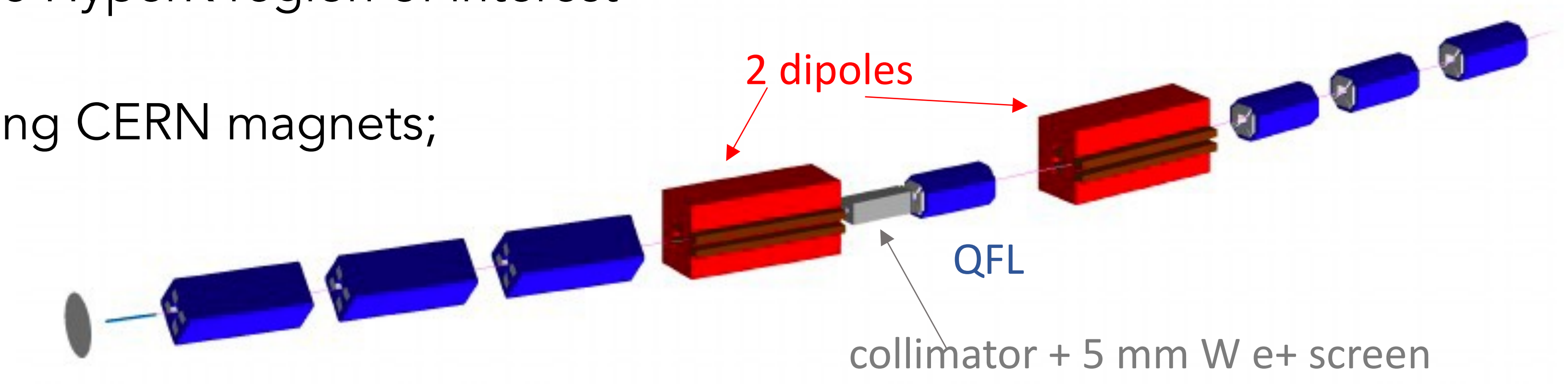
- ➢ final position will be optimized to reduce neutrinos produced here and crossing detector;

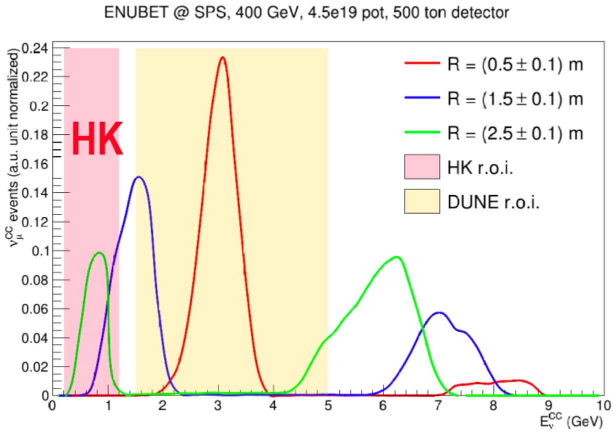
Transfer line R&D

Multi-momentum transfer line: 4, 6 & 8.5 GeV

- ➢ would allow to explore also the HyperK region of interest at lower energy;
- current design based on existing CERN magnets;

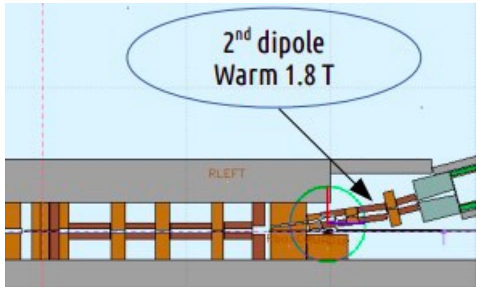
optics optimization: TRANSPORT & G4beamline. Results will be validated with MADX/PTC-TRACK: estimate high-order effects. Background reduction studies: with FLUKA.

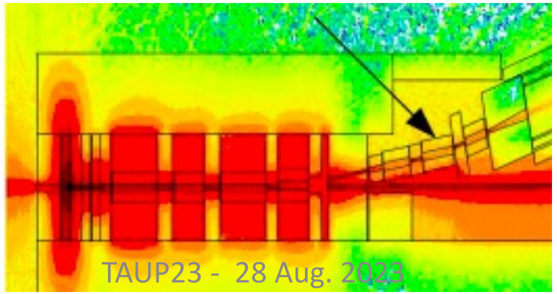




Super conducting dipole:

- ➢ could achieve a better separation of the taggable ν_e component from the non taggable one;
- investigating possibility for 2nd dipole: static transfer line fully implemented in FLUKA to estimate ionizing doses and neutron fluence;



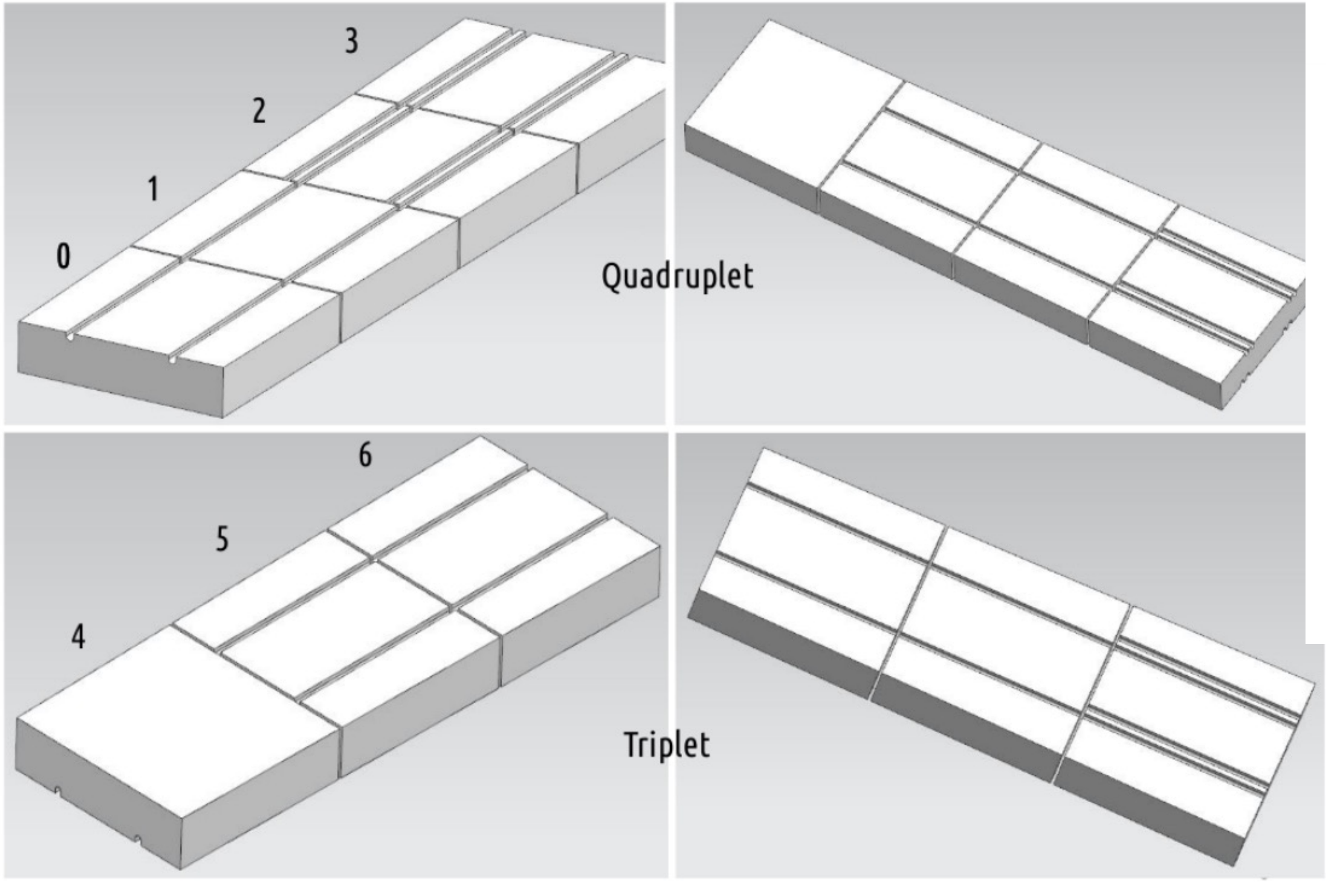


For a 2s spill 0.055 mJ/cm³ => 0.027 mW/cm³ during the 2s slow extraction: looks safe, from LHC studies critical power much higher

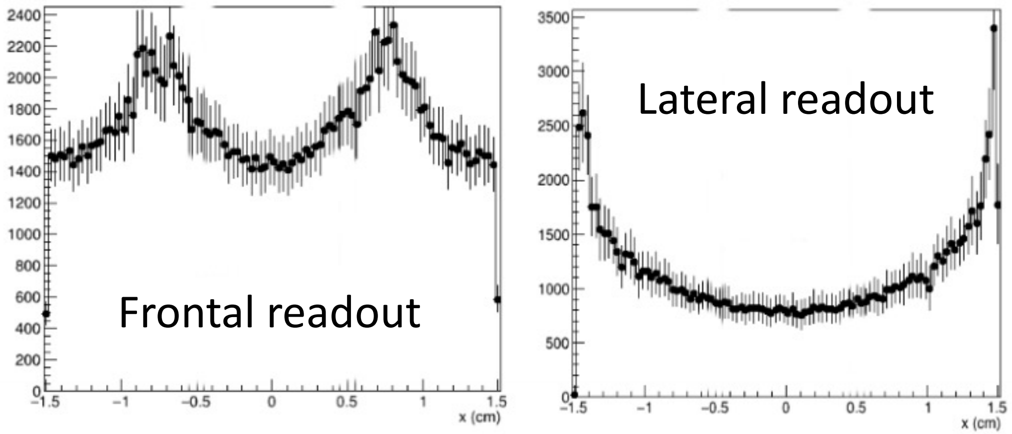
https://journals.aps.org/prab/pdf/10.1103)/PhysRevSTAB.18.061002)

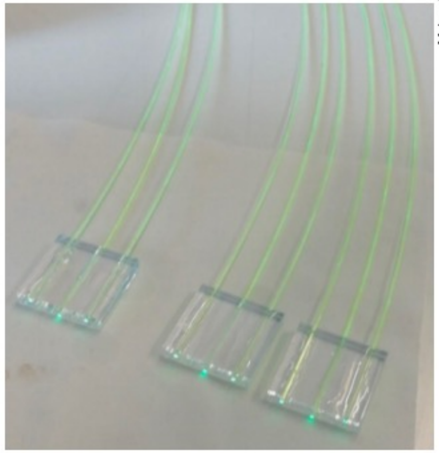
New light readout scheme

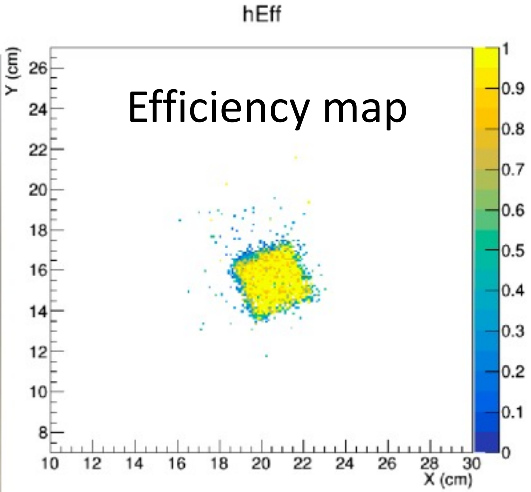
- moved from lateral to frontal light readout;
- safer production: injection molding => transit grooves milled => surface treatment (chemical etching) => readout grooves milled;
- better uniformity and higher efficiency;



GEANT4 optical simulation







Tests with cosmic rays