This project has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (grant agreement N. 681647)

NP06/ENUBET
60 physicists, 12 institutions

The ENUBET experiment

Claudia Caterina Delogu, University of Padova & INFN,
on behalf of the ENUBET Collaboration

NP06/ENUBET

Enhanced NeUtrino BEams from kaon Tagging

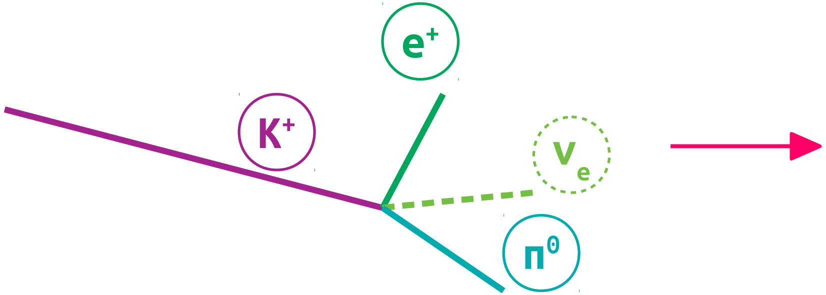
Future neutrino physics will require measurements of absolute neutrino cross sections at the GeV scale with 1% precision

Leading source of uncertainty in cross-section measurement: neutrino flux

→ dominated by the uncertainty on the simulation of the beamline and the hadro production data

Measure the number of leptons that are produced in a decay tunnel: one-to-one relationship between the lepton that you produce and the neutrino.

ENUBET: $K^+ \rightarrow \pi^0 e^+ \nu_e$



Monitored neutrino beam

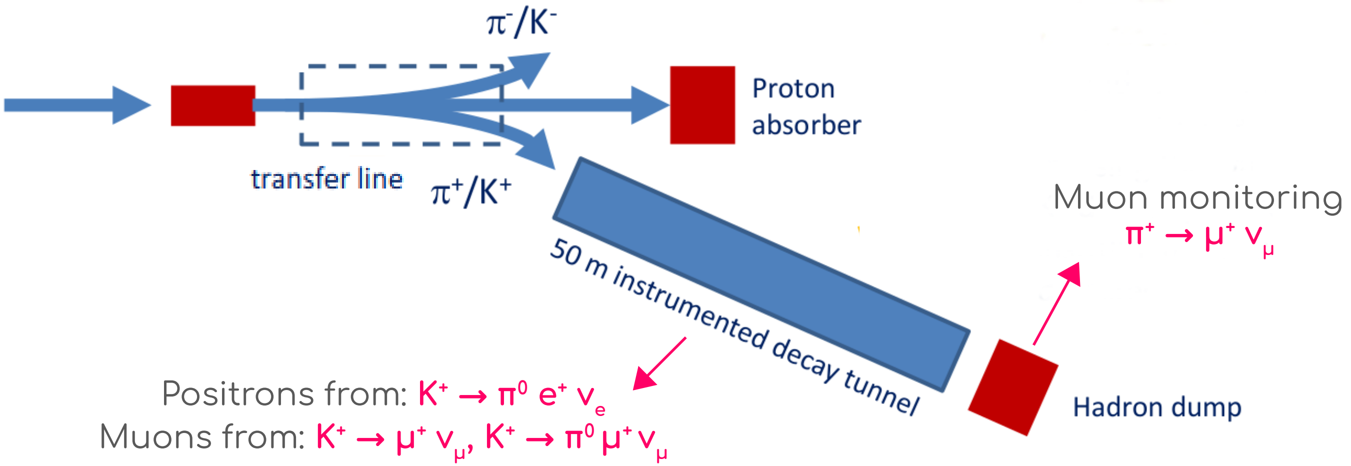
A. Longhin, L. Ludovici, F. Terranova, EPJ C75 (2015) 155

ENUBET

Design optimized to reach a 1% systematic error on measurement of the flux and of the cross-sections of the electron neutrino

Two main steps:

- layout of the π/K focusing and transport system with suitable proton extraction schemes
- special instrumented beamline capable of performing positron monitoring from decays of K in a ν beam decay tunnel at single particle level



ENUBET beamline

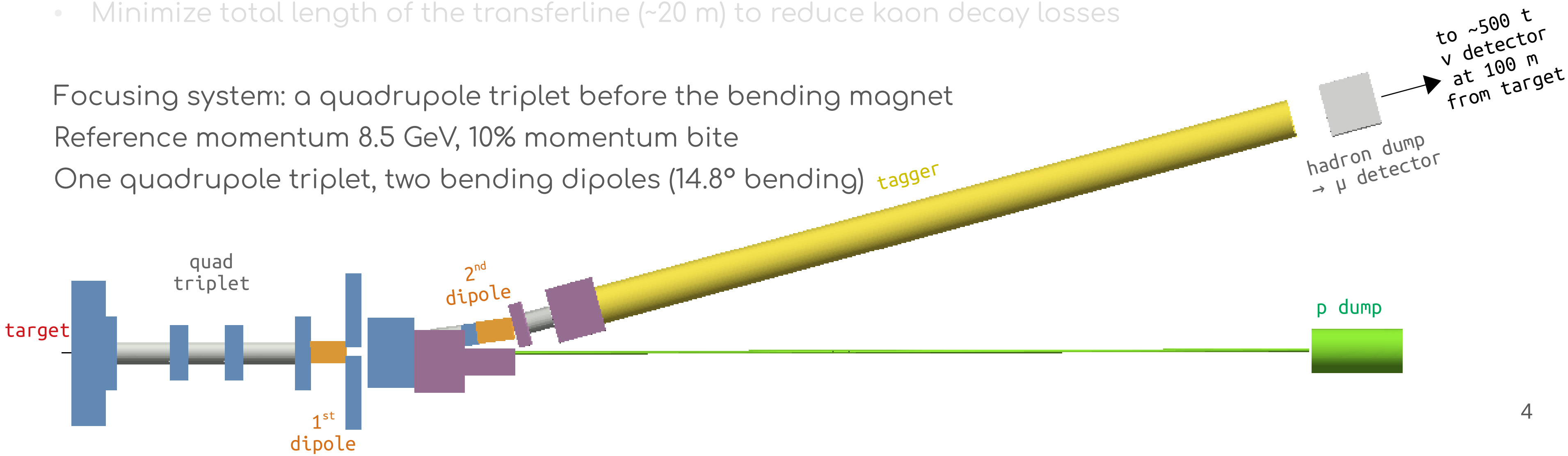
Requirements:

- Use of conventional magnet field and apertures (normal-conducting, aperture < 40cm)
- Keep under control level of background transported to the tunnel
- Small beam size: non decaying particles should exit the decay pipe without hitting the walls
- Maximize number of K^+ at tunnel entrance
- Minimize total length of the transferline (~20 m) to reduce kaon decay losses

Focusing system: a quadrupole triplet before the bending magnet

Reference momentum 8.5 GeV, 10% momentum bite

One quadrupole triplet, two bending dipoles (14.8° bending)



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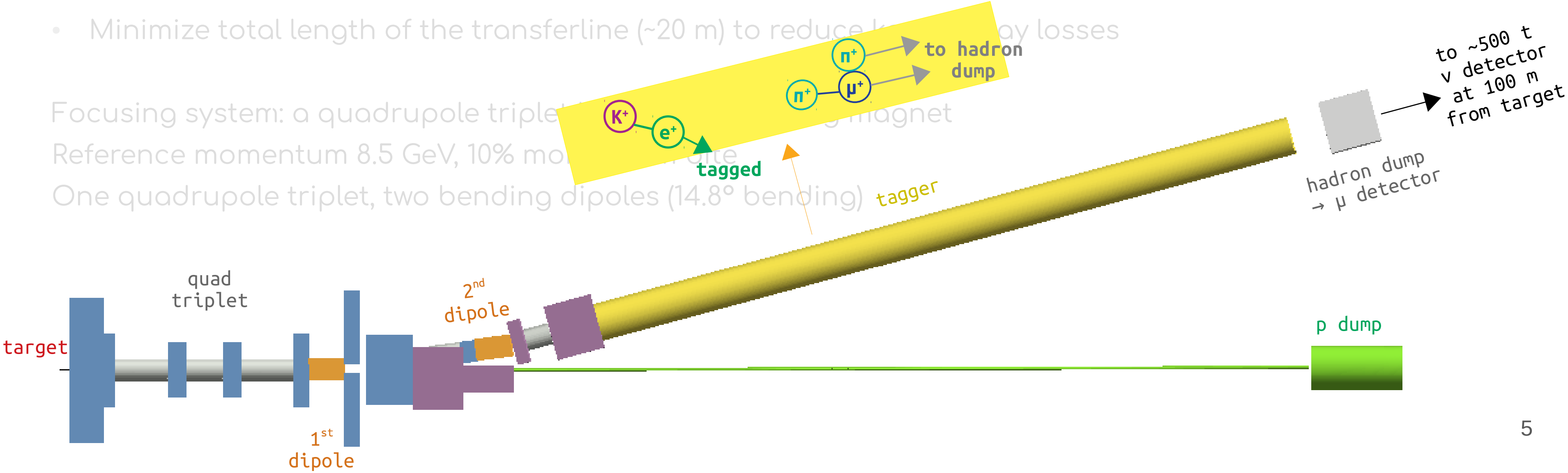

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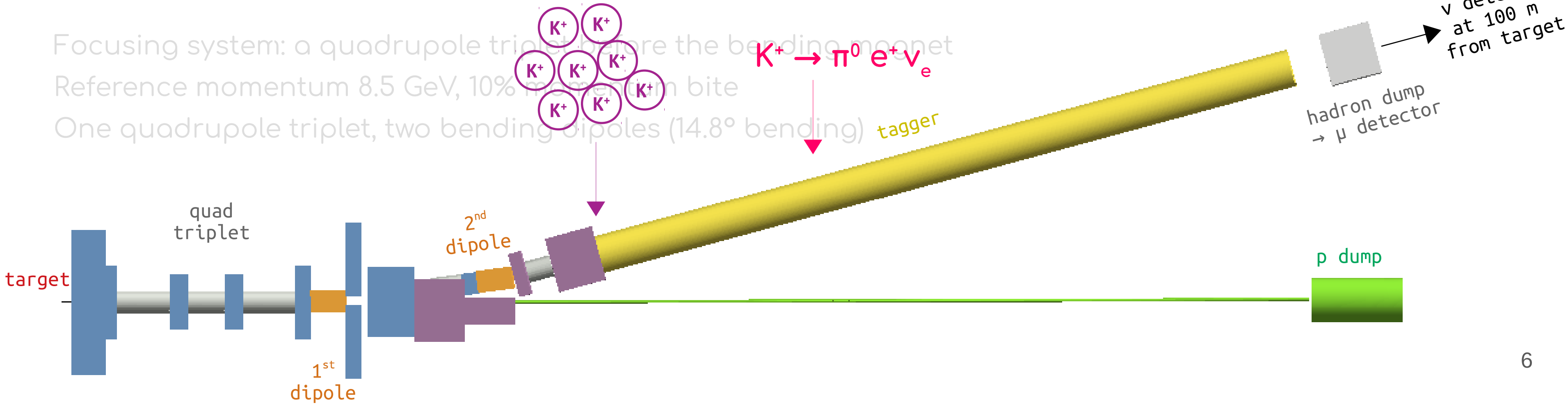

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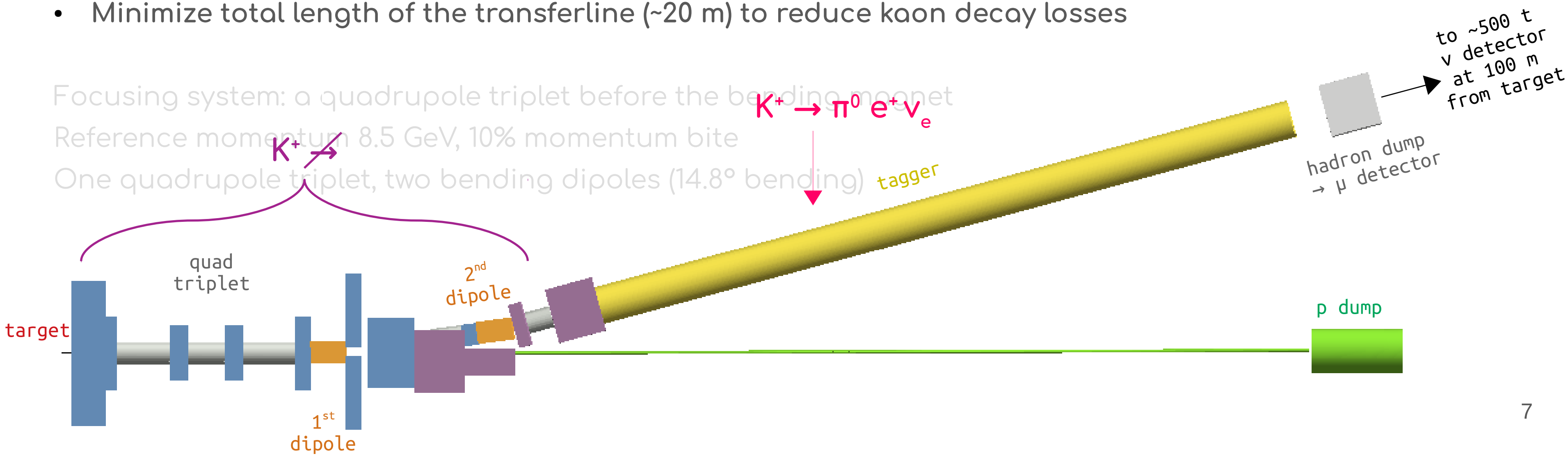

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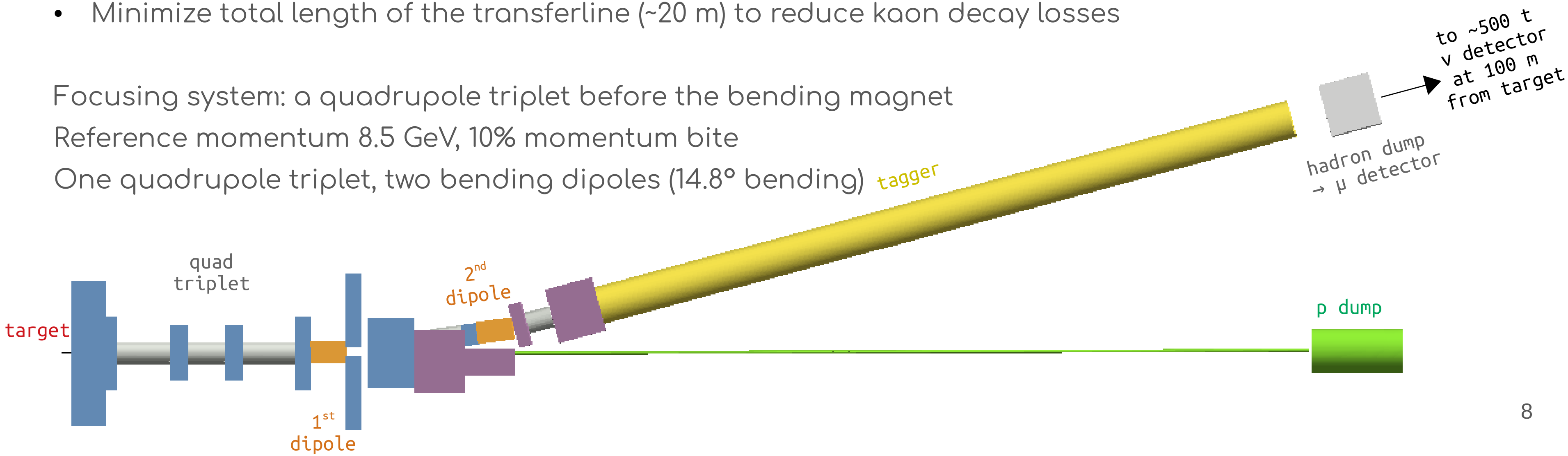


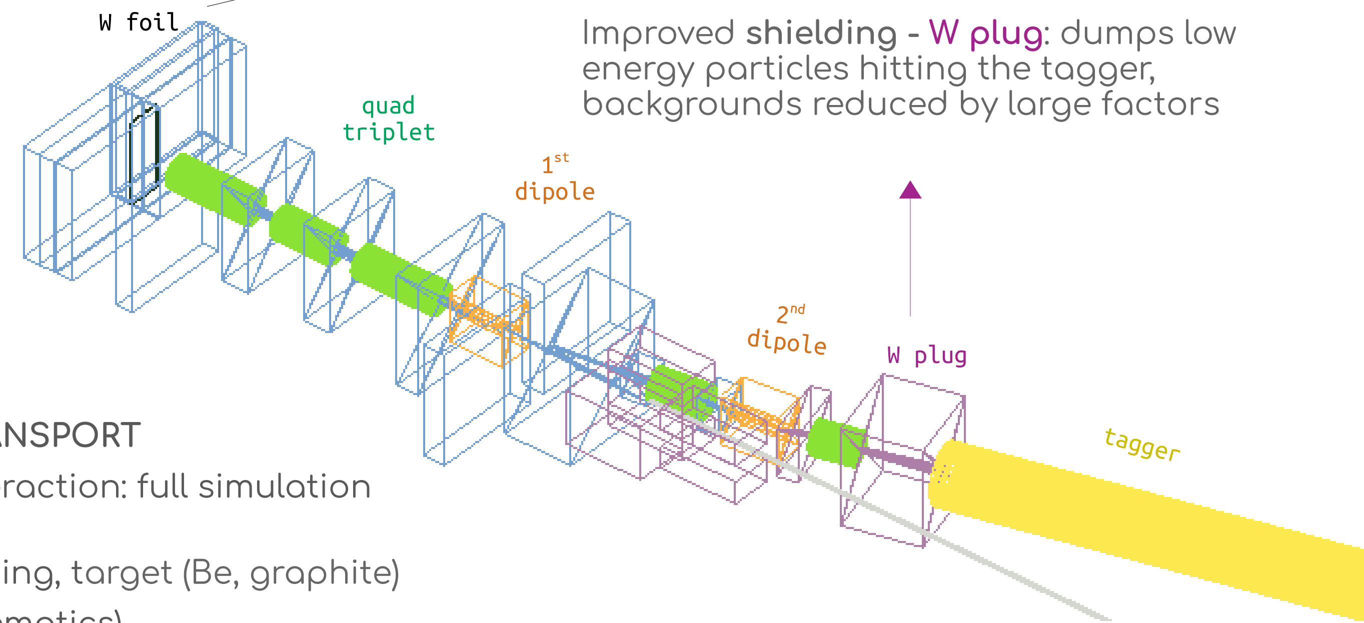
ENUBET beamline

Larger bending angle w.r.t. original proposal (single dipole beamline)

- increased length
- better collimated beam
- reduced backgrounds

Improved **shielding - W foil**: dumps low energy e^+ entering tunnel

Improved **shielding - W plug**: dumps low energy particles hitting the tagger, backgrounds reduced by large factors

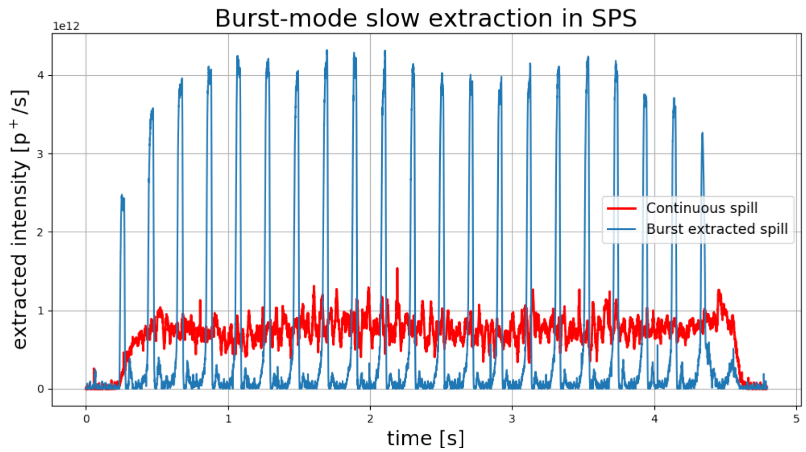


- Optics: optimized with **TRANSPORT**
- Particle transport and interaction: full simulation with **G4Beamline**
- **FLUKA**: doses and n shielding, target (Be, graphite)
- In progress: **GEANT4** (systematics)

Horn-based beamline - “burst slow extraction”

Magnetic horn placed between the target and the quadrupoles, pulsed with large currents (2-10 ms pulse, 180 kA at 10 Hz)

“Burst slow extraction”: small bursts of 10 ms, repeated with a frequency of 10Hz during the flat top of the accelerator.



Tested at the SPS at CERN in 2018: 20 ms achieved

Today:

- **Simulation** → 2-10 ms
  → to be tested after LS2 (2022)
- Reoptimization of the horn **geometry**: conductor and currents

Static focusing option: single resonant slow extraction → less challenging (no need synchronise proton extraction with current pulsing)

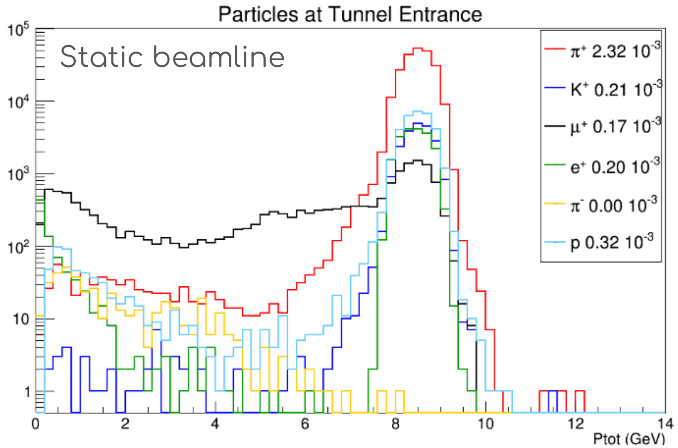
CERN-BE-OP-SPS, F.Velotti, M.Pari, V.Kain, B.Goddard

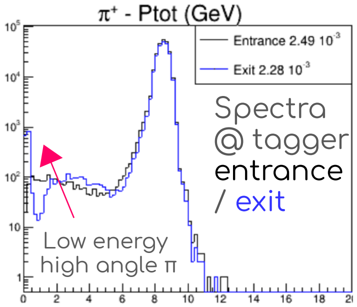
Particle yields

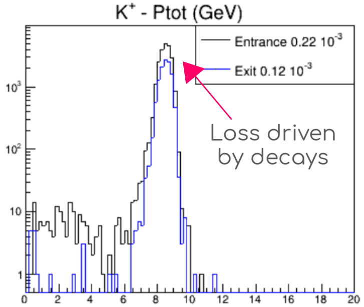
The horn-based option allows ~ x5 faster statistics, but the static transferline offers several advantages

- No need for fast-cycling horn
- Strong reduction of the rate (pile-up) in the instrumented decay tunnel
- Monitor μ after the dump at % level (flux of ν_μ from π)

Initial estimates were ~ x4 too conservative wrt present simulations
→ configuration still under optimization





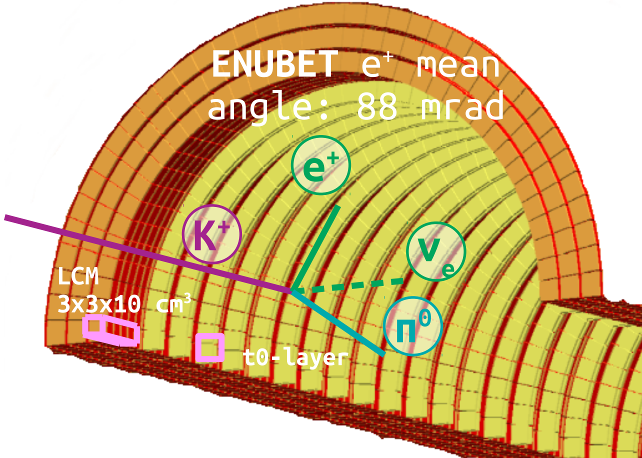


Focusing system	π/pot (10^{-3})	K/pot (10^{-3})	Extraction length	π/cycle (10^{10})	K/cycle (10^{10})	Proposal (*)
Horn	97	7.9	2 ms	438	36	x 2
Static	19	1.4	2 s	85	6.2	x 4

To be updated with the new beamline

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

Instrumented decay tunnel



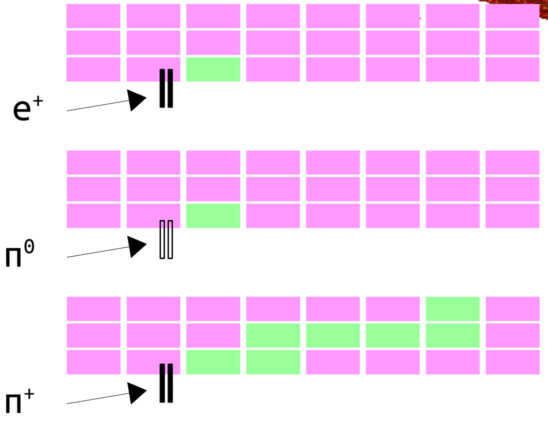
Calorimeter → Longitudinal segmentation (three radial layers, plastic scintillator + iron absorber)
→ $e^+/\pi^+/\mu$ separation

Light readout system SiPMs on top of the calorimeter, above a borated polyethylene shield

Lateral light readout system: WLS fibers running along the edges of the tiles → reduced (x18) neutron damage the SiPMs

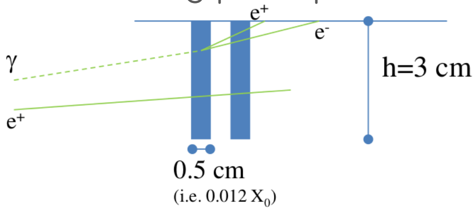
Photon veto Plastic scintillator tiles arranged in doublets forming inner rings
→ π^0 rejection

Event topology:



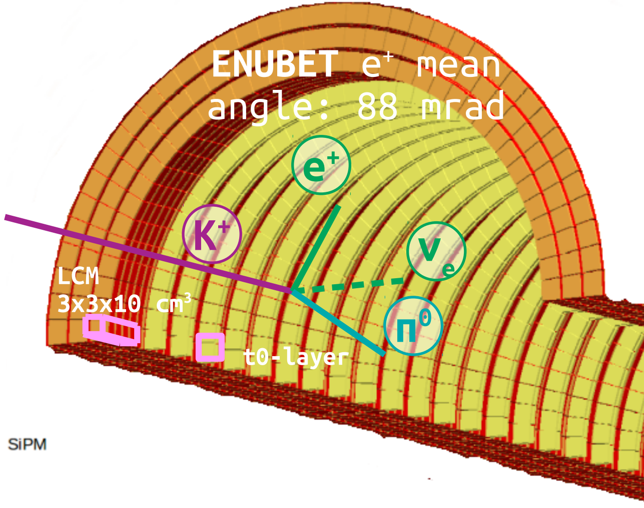
September 2018 @ CERN-PS: response to MIP, e and π tested for a calorimeter prototype and an integrated t_0-layer.

Photon veto working principle



F. Acerbi et al, JINST 15 (2020) P08001

Instrumented decay tunnel



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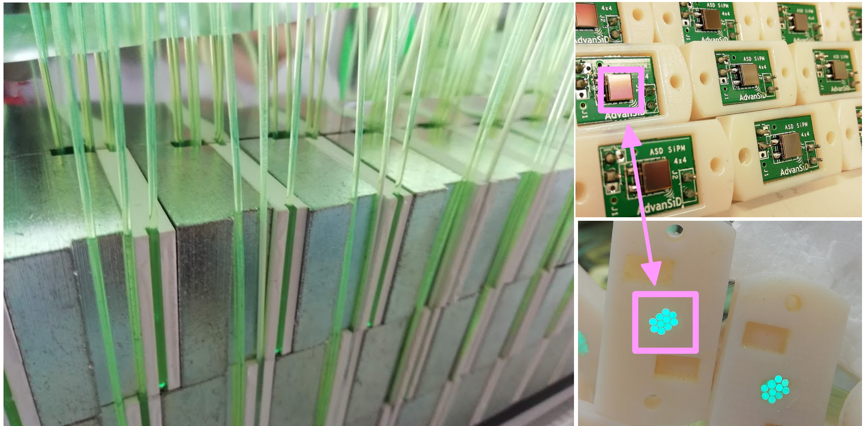
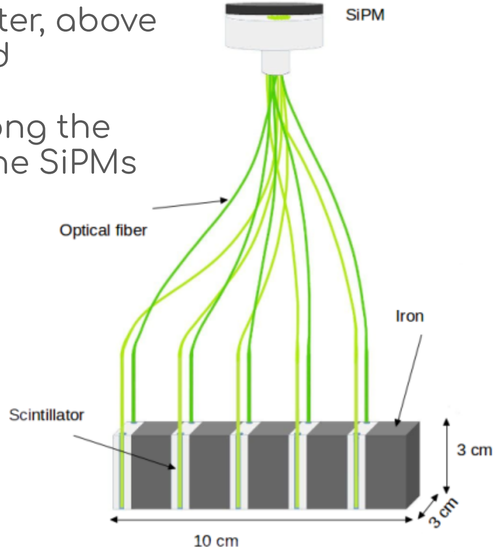
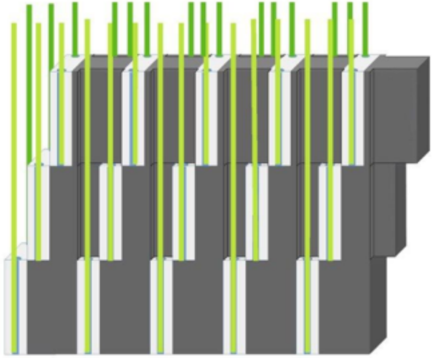




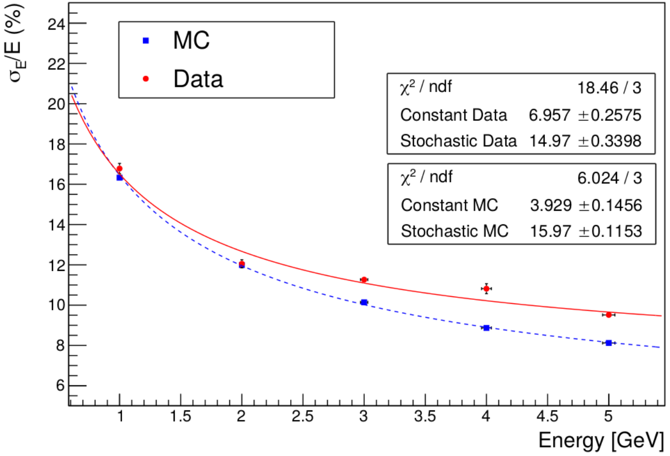


F. Acerbi et al, JINST 15 (2020) P08001

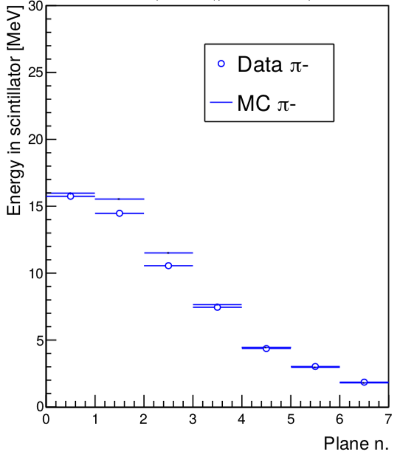
Testbeam results

September 2018 @ CERN-PS: response to MIP, e and π tested for a calorimeter prototype and an integrated t_0-layer

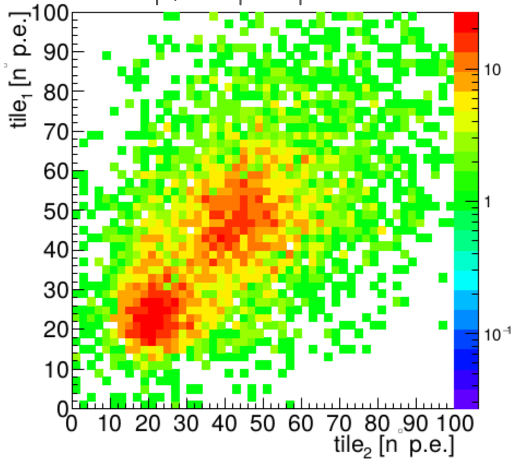
Energy resolution

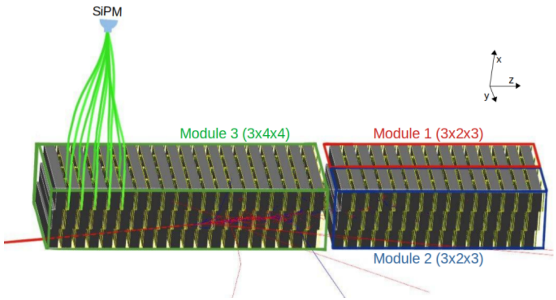


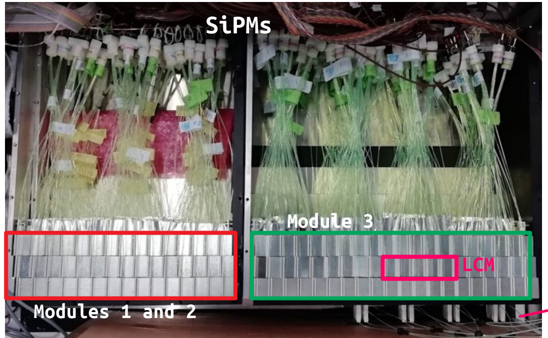
π energy vs shower depth (planes)

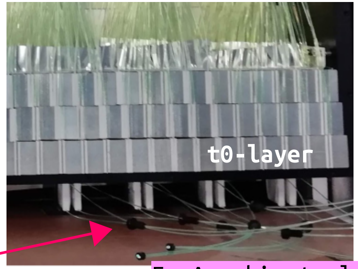


1mip/2mip separation







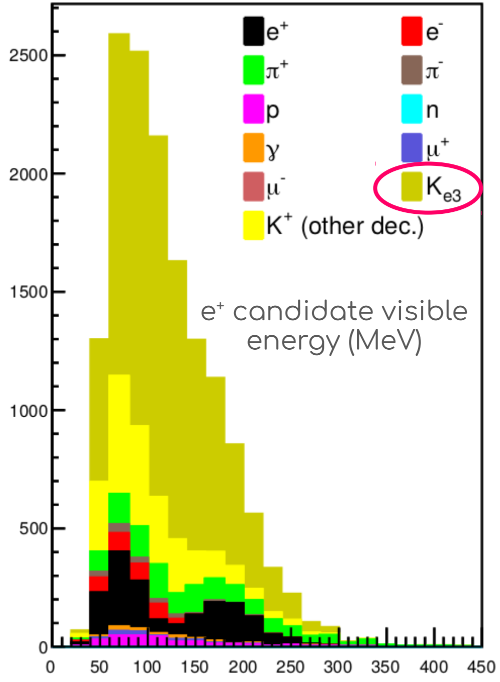


F. Acerbi et al, JINST 15 (2020) P08001

Positron reconstruction

Full GEANT4 simulation of the detector, validated by prototype tests at CERN during 2016-2018.

- particle propagation and decay from transfer line to detector
- hit level detector response
- pile-up effects included



Analysis chain:

- **Event builder →** identify the seed of the event (LCM with largest energy deposit in inner layer and of E>28 MeV). Cluster neighbour LCM deposits compatible with propagation of shower
- **e/π/μ separation →** multivariate analysis exploiting 19 variables (energy pattern deposition in calorimeter, event topology, and photon-veto energy deposition)
- **e/γ separation →** signal on the tiles of the photon veto (0-1-2 mip)

S/N = 2.1

Efficiency: 24% (dominated by geometrical efficiency)

Flux components

Assumption: 500 t neutrino detector located 50 m from the hadron dump

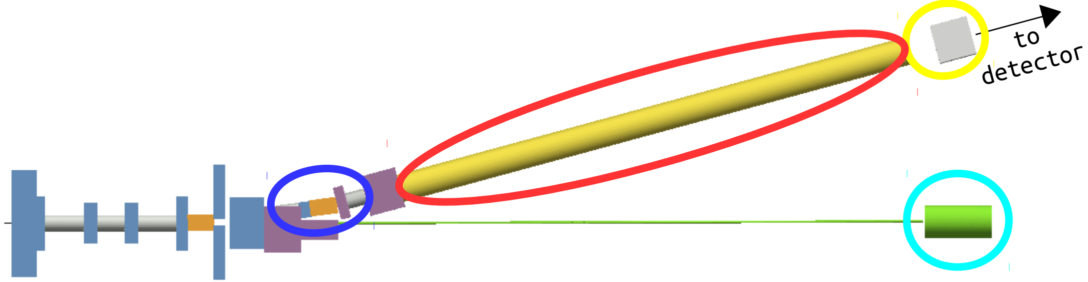
→ 10^4 fully reconstructed ν_e CC in about 1.5 y of data taking

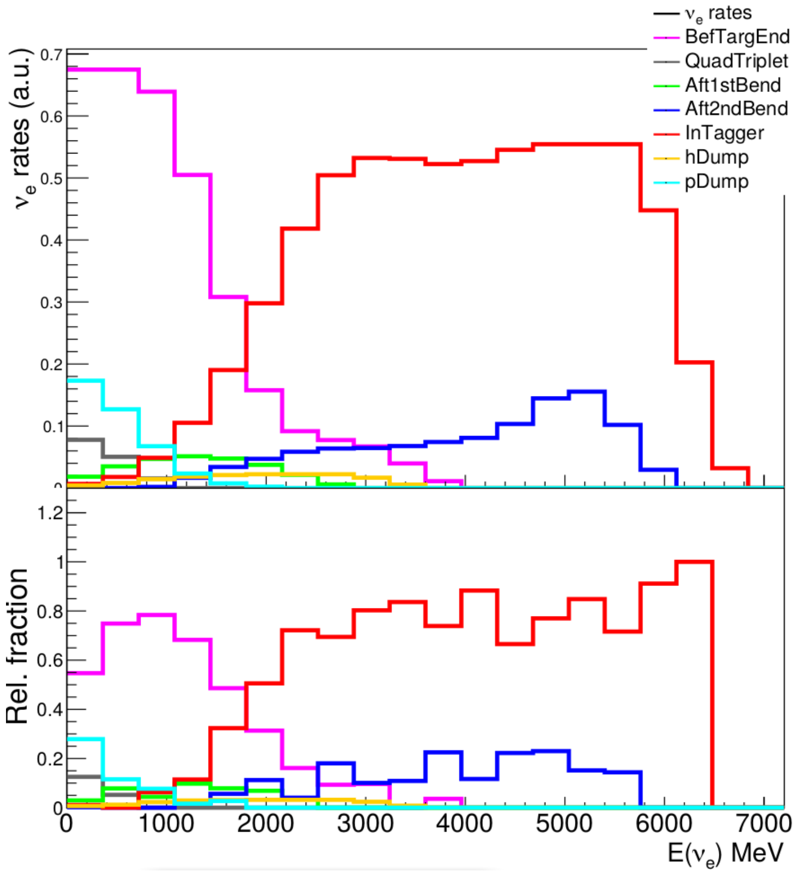
Events:

- 80% directly monitored (positrons in the decay tunnel)
- 10% from decay in the transfer line (straight section in front of the tagger, pointing to the detector)

  → removable with simulation
- 10% low energy events from arly decays of kaons

  → removable with energy cut.





Muon neutrinos (in progress)

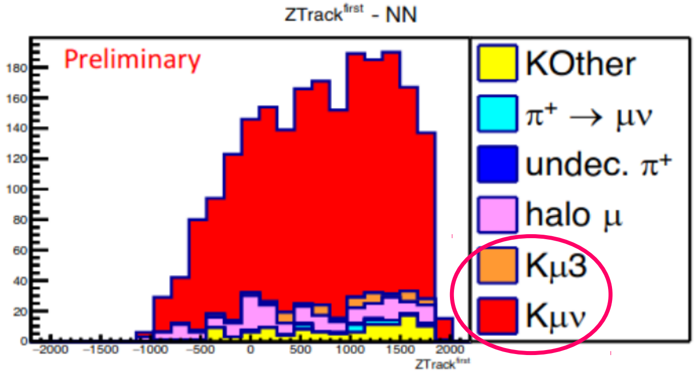
High-Energy: $K^+ \to \mu^+ \nu_\mu$, $K^+ \to \pi^0 \mu^+ \nu_\mu$ → constrained by the tagger

Low-Energy: $\pi^+ \to \mu^+ \nu_\mu$ → constrained by detctors following the hadron dump

$K^+ \to \mu^+ \nu_\mu$ Efficiency = 35% S/N = 6.1

$K^+ \to \pi^0 \mu^+ \nu_\mu$ Efficiency = 21% S/N = 6.1

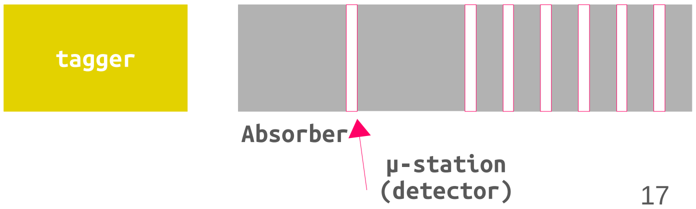
- **Event builder** → identify seed of the event (inner layer LCM withm E = 5-15 MeV). Cluster all LCM deposits compatible with muon-track topology and propagation
- **μ-like background separation** → multivariate analysis exploiting 13 variables (energy deposition, track isolation and topology)



$\pi^+ \to \mu^+ \nu_\mu$

Muon stations after hadron dump: pions have a large forward boost, muons from decays exit the tunnel.

Estimation of muon and neutron rates in progress → choice of detector technology

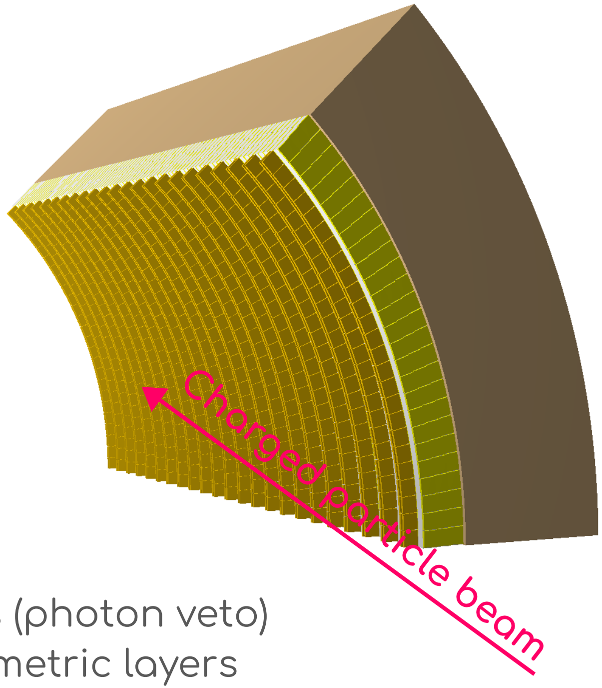


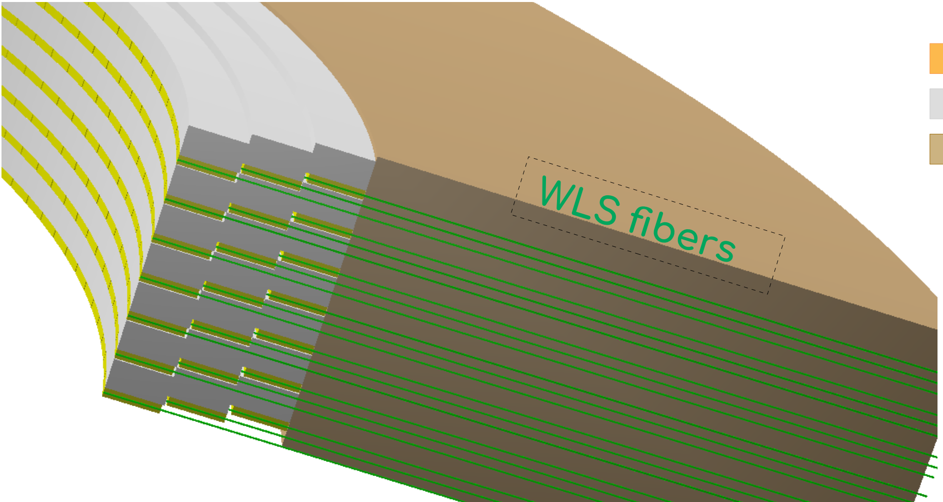
The ENUBET demonstrator

- Length ~ 3m
- Fraction of Φ

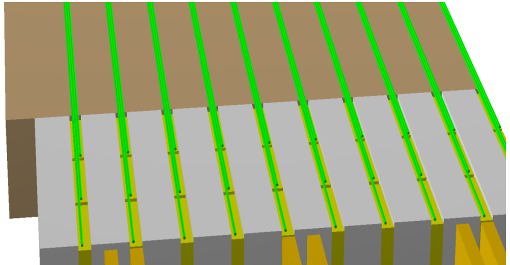
Due by 2021, it will allow the containment of shallow angle particles in realistic conditions

Validation: East Area beamline at CERN





t_0-layers (photon veto)
3 calorimetric layers
shielding



Conclusions & next steps

2016 → today:

- Simulation of the beamline
- Tested the "burst" slow extraction scheme at the CERN-SPS
- Feasibility of a purely static focusing system (10^6 ν_μ^{CC} , 10^4 ν_e^{CC} /y/500 t)
- Positron reconstruction: single particle level monitoring
- Testbeams campaign before LS2

Reduction of the uncertainty in the flux

→ New generation of short-baseline experiments

→ Support from the European Strategy

Conclusions & next steps

2020 ✔

- ✔ The design phase is over
- ✔ The simulations are nearly completed

Work in progress

- ✔ Horn optimization
- ✔ Update of flux and spectra with the final beamline
- ✔ Establish the final systematic budget

2021

- ✔ Construction of the demonstrator
- ✔ Full assessment of systematics

2022

- ✔ Test of the demonstrator

Thank you!

http://enubet.pd.infn.it/