Prepared by A. Longhin, (INFN-LNF, andrea.longhin@lnf.infn.it) for the Frontiers Detectors for frontiers Physics Conference, La Biodola, Isola d'Elba (Italy), 24-30 May 2015.

A new-concept calorimeter for future neutrino beams based on Kaon tagging

A. Longhin (INFN-LNF)
L. Ludovici (INFN-RM1)
F. Terranova (Univ., INFN MIB)

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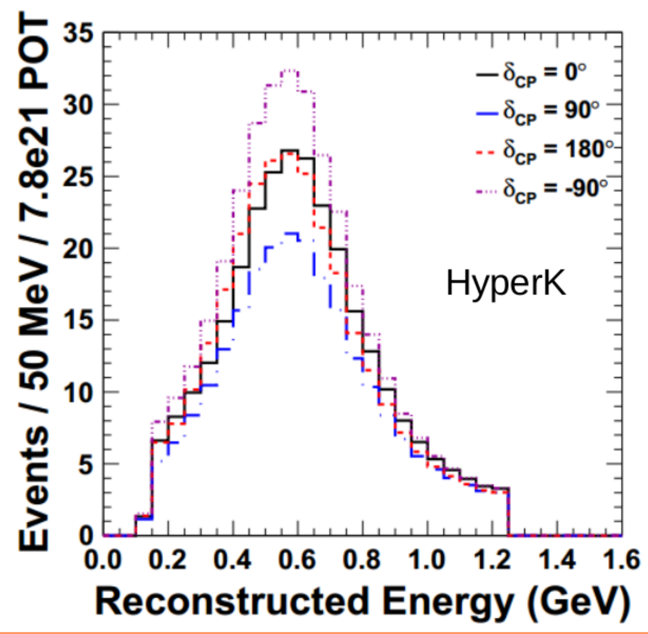
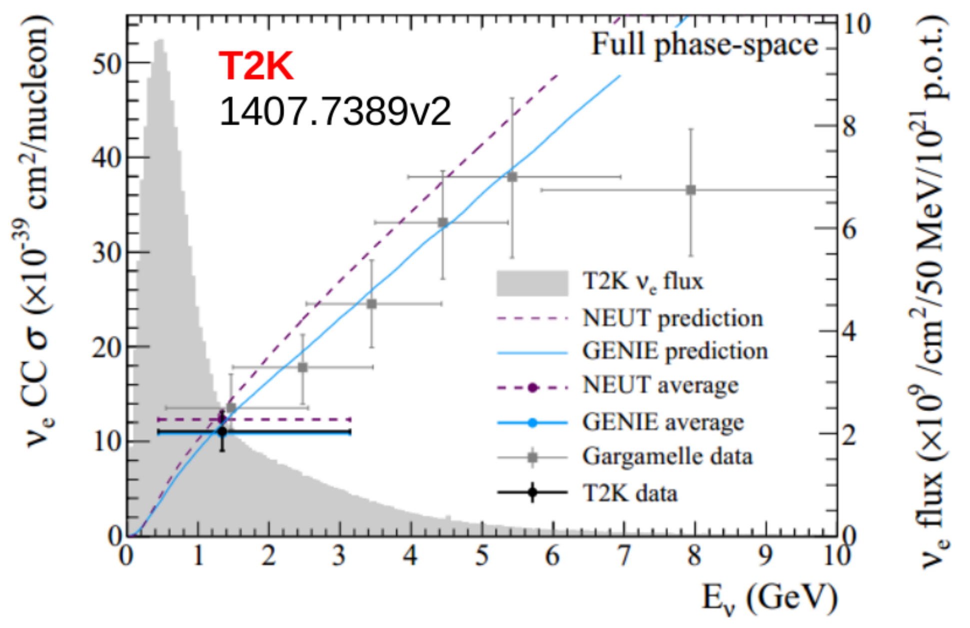
Introduction, physics goals

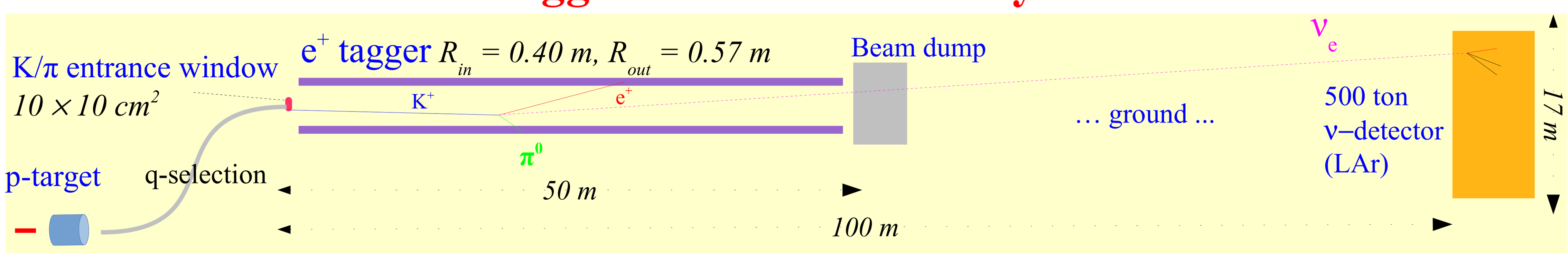
- Measurement of **leptonic CP violation**: modulations in the energy spectrum of ν_e from $\nu_\mu \to \nu_e$: **knowing well the ν_e cross section is crucial**
- International experiments based in JP (Hyper-Kamiokande) or in the US (DUNE)
- Current mesurements (Gargamelle, T2K) **limited by systematics in the neutrino flux for conventional neutrino beams** (~10% normalisation error)

→ A new-generation ν source based on tagging of e^+ from K_{e3} decays $K^+ \to e^+ \pi^0 \nu_e$





Tagged neutrino beam layout



Focusing: magnetic horn

Transport/focusing beamline ouput:
- K^+/π^+ 8.5 GeV/c ± 20% θ < 3 mrad

- 10^4 ν_e^{CC} from 1.94×10^{17} K^+
- 85% of e^+ with a ν_e crossing the far detector

ν_e flux proportional to the e^+ rate in the tagger

ν_e flux will NOT depend on hadro-production, K/π production ratio, Protons on Target (PoT), 2^{ry} beamline efficiency **but only on:** the **geometrical acceptance** of the e^+-tagger/ν-detector, the **e^+ tagger efficiency** and the **mastering of residual backgrounds** →

O(1%) systematic error achievable

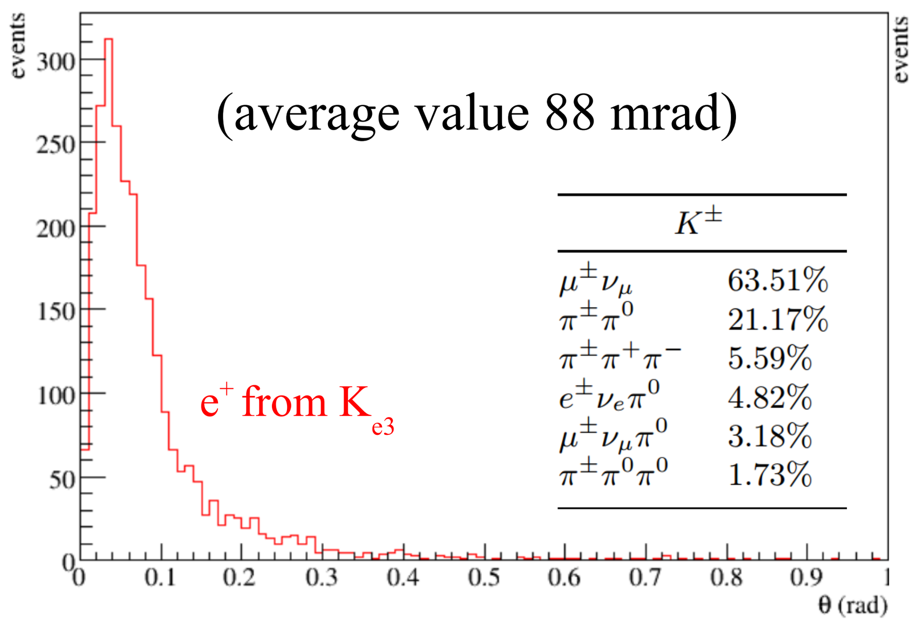
→ ν_e^{CC} precision measurement

Particle rates in the tagger

(with 10^{10} focused π^+/spill)

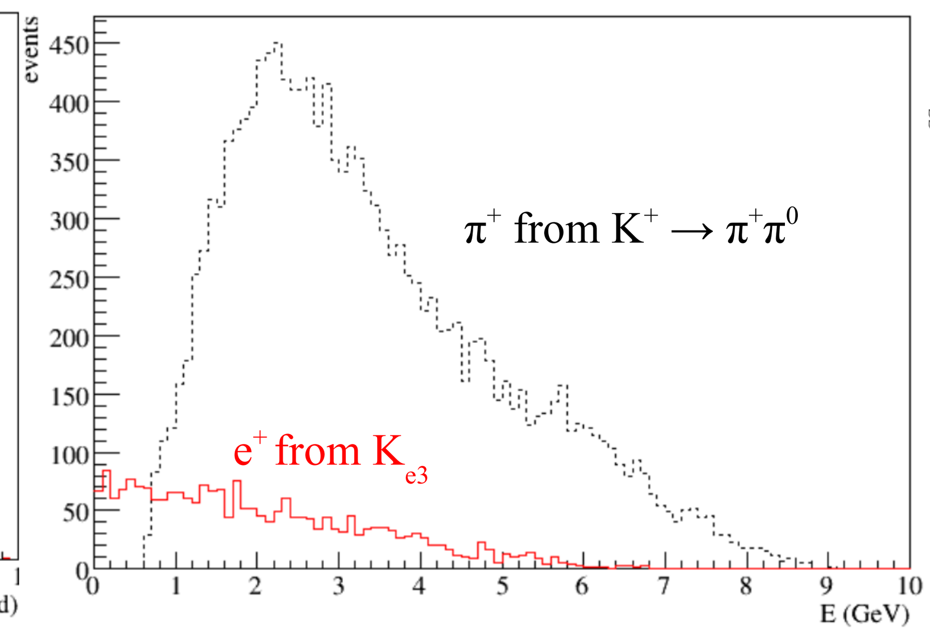
particle	Max. (kHz/cm²)
μ^+	190
γ	190
π^+	100
K^+	20
all	**0.5 MHz/cm²**

e^+ angular distribution

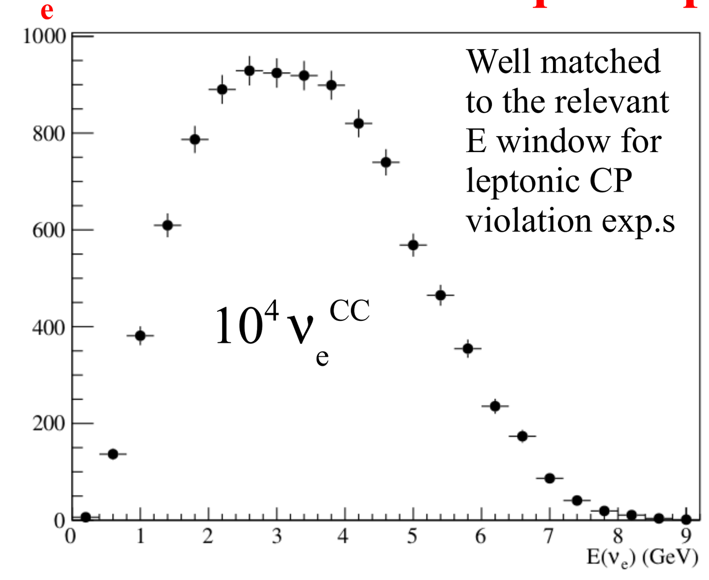


$K^\pm$	
$\mu^\pm\nu_\mu$	63.51%
$\pi^\pm\pi^0$	21.17%
$\pi^\pm\pi^+\pi^-$	5.59%
$e^\pm\nu_e\pi^0$	4.82%
$\mu^\pm\nu_\mu\pi^0$	3.18%
$\pi^\pm\pi^0\pi^0$	1.73%

e^+/π^+ energy distribution



ν_e^{CC} rates on 500 t + required prot. on target



E(prot.) GeV	PoT for 10^4 ν_e^{CC} (10^{20})**
30	5.0
50	2.4
60	2.0
70	1.76
120	1.16
450	0.52

~ few years run

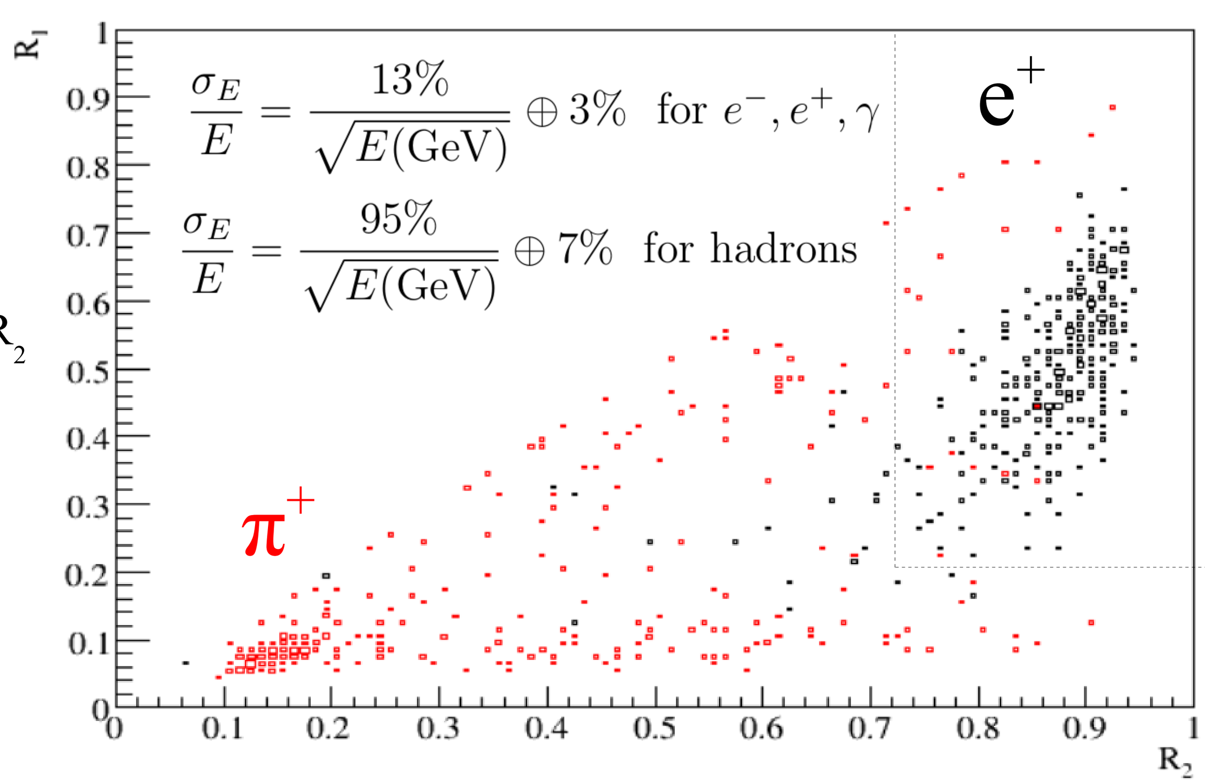
** Proton/kaon ratio based on an estimate of the π/K collection efficiency using a focusing/transport beamline equipped with a pulsed magnetic horn

e^+/π^+ separation

$R_{1,2} = E_{1,2}/E_{tot}$

$E_{1,2}$: energy deposited in a cylinder with radius $2R_{Molière}$ (3.2 cm for Cu) and height $5X_0$ for R_1 or $10\ X_0$ for R_2 (7.2 and 14.4 cm)

Cut	Efficiency
K_{e3} decay	100%
e^+ in calorimeter	85%
R_1,R_2 cuts	67%
$E_{tot} > 300$ MeV	59%



$$\frac{\sigma_E}{E} = \frac{13\%}{\sqrt{E(\text{GeV})}} \oplus 3\% \quad \text{for } e^-, e^+, \gamma$$

$$\frac{\sigma_E}{E} = \frac{95\%}{\sqrt{E(\text{GeV})}} \oplus 7\% \quad \text{for hadrons}$$

Background budget

Source	BR	Misid	$\epsilon_{X\to e^+}$	Contamination
$\pi^+ \to \mu^+\nu_\mu$	100%	$\mu \to e$ misid.	<0.1%	neglig. (outside acceptance)
$\mu^+ \to e^+\bar{\nu}_\mu\nu_\mu$	DIF	genuine e^+	<0.1%	neglig. (outside acceptance)
$K^+ \to \mu^+\nu_\mu$	63.5%	$\mu \to e$ misid.	<0.1%	negligible
$K^+ \to \pi^+\pi^0$	20.7%	$\pi \to e$ misid.	2.2%	13%
$K^+ \to \pi^+\pi^+\pi^-$	5.6%	$\pi \to e$ misid.	3.8%	5%
$K^+ \to \pi^0\mu^+\nu_\mu$	3.3%	$\mu \to e$ misid.	<0.1%	negligible
$K^+ \to \pi^+\pi^0\pi^0$	1.7%	$\pi \to e$ misid.	0.5%	negligible

Main contribution from **π → e mis-id**.

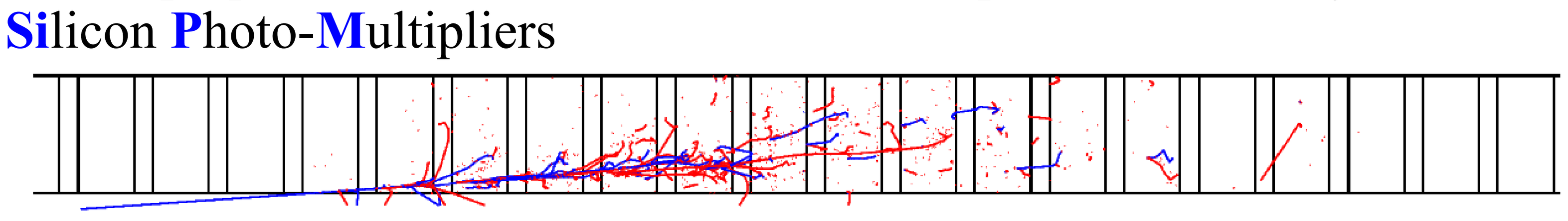
The positron tagger has to achieve a few % e/π separation in the harsh environment of a 50 m long decay tunnel →

Requirements and challenges for the positron tagger

Granularity → e/π rejection at the few % level with a reasonable amount of channels (the tagger is 50 m long !)
Geometrical layout → Extended source with non definite incoming direction
Fast response → for a 10 cm² surface, keeping the pile-up probability below 5% requires a recovery time below 10 ns
Radiation tolerance → Integrated dose during a few years < 1.3 kGy

Proposed technology

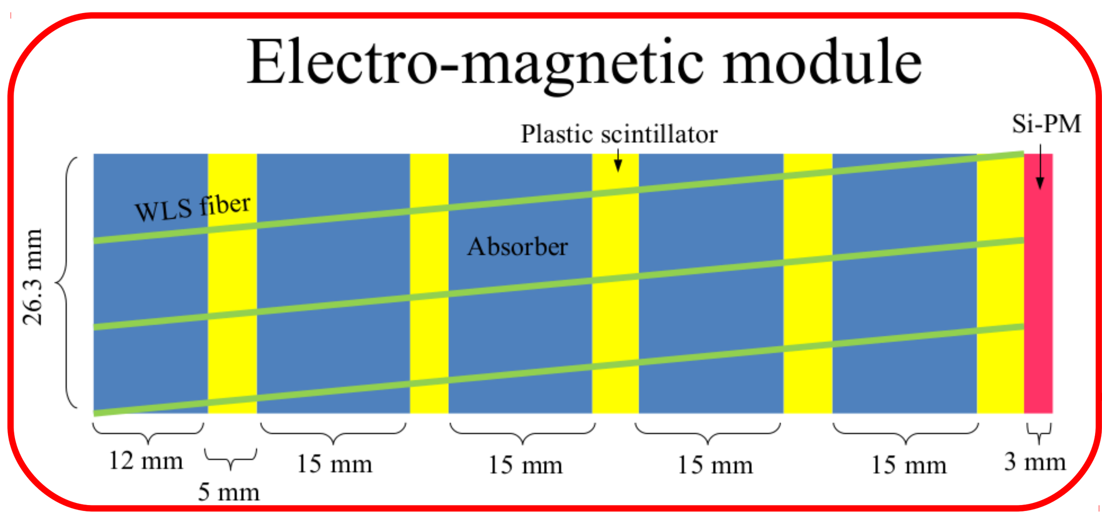
Shashlik calorimeter (0.5 cm scintillator tiles + 1.5 cm Copper slabs)
Wave Length **S**hifting **fibers** running along the average e^+ direction (i.e. almost perpendicular to the tiles) with ~1 cm pitch, read-out by small area **Si**licon **P**hoto-**M**ultipliers



A 2 GeV positron impinging on the shashlik calorimeter with an 88 mrad angle (GEANT4)

Tagger structure and modularity

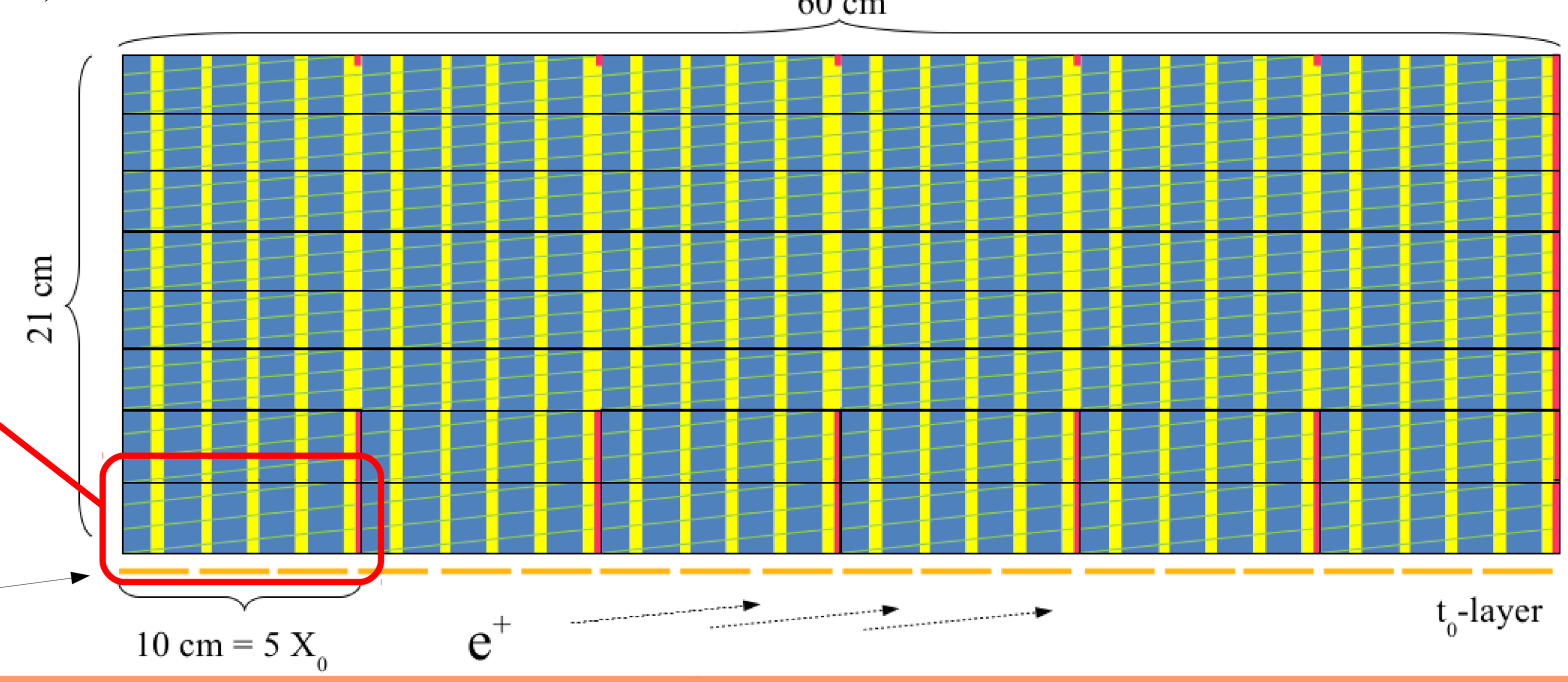
Radial views (the 2π geometry is obtained with 76 azimuthal modules)



Thin tracking layer (t_0-layer) to tag π^0 initiated e.m. showers

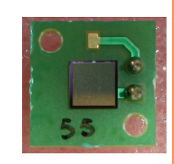
Full module

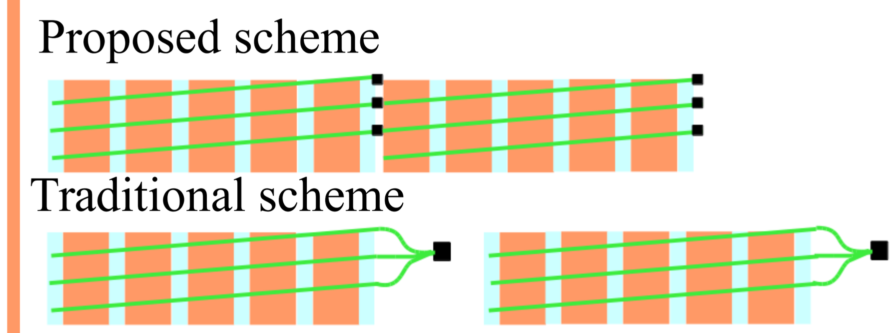
2 inner layers = 2 x 6 e.m. modules
6 outer layers = hadronic modules



Improving the longitudinal sampling uniformity

Couple each fiber to a small SiPM to get rid of dead zones introduced by fiber bundling





Summary

- **Fast, radiation hard detectors** allows for a **reconsideration of the tagged neutrino beams** idea. A **realistic setup** has been proposed for the first time.
- **Reduced systematics** in the **neutrino flux → σ(ν_e) at 1% with a 0.5 kt ν-detector + reasonable PoT** (0.5-5x10^{20}).
- 2^{nd} phase: with long proton extractions, O(1) s, and continuous beam focusing devices (i.e. large aperture quads.): **event-by-event time tagging** might also become viable.

Prospects

- **Full GEANT4 simulation** is in progress.
- Construction of **prototypes for the electro-magnetic module** and **test-beam at CERN with π/e beams** planned.
- A **3 m long demonstrator** (**ENUBET**, **E**nhanced **N**e**U**trino **BE**ams with kaon **T**agging) possibly at the **CERN ν platform** is envisaged.
- A **working group** is forming. Open to interested parties!

Questions ?

On-site …

… or to …

andrea.longhin@lnf.infn.it
lucio.ludovici@roma1.infn.it
francesco.terranova@mib.infn.it