ESS neutrino Super Beam plus

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WP6 report
Low-Energy Monitored Neutrino Beam

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Istituto Nazionale di Fisica Nucleare

ESSnuSB+ 2nd Annual meeting
Hamburg University
26/09/2024

State of the art
(as of monday)

Summary

WP6 is aimed at the design of a Monitored Neutrino Beam that will run before the long baseline experiment, i.e. in the construction phase of the ESSnuSB accumulator to perform high precision cross section measurements below 1 GeV. As a consequence, the most important question we addressed at the start of the project is: is it possible to perform this measurement without any LINAC upgrade (2 GeV, 2.86 ms)? **We can now safely claim that the answer is positive.**

Main achievement in the last 12 months:

- Full simulation of the instrumented tunnel
- Particle identification algorithms for muons from pion decay
- Detector technologies

F. Terranova Intro

Indeed we shoud envisage a factor 8 reduction of the spill intensity ($1x10^{14}$ pot/spill) to avoid pile-up to the tunnel instrumentation

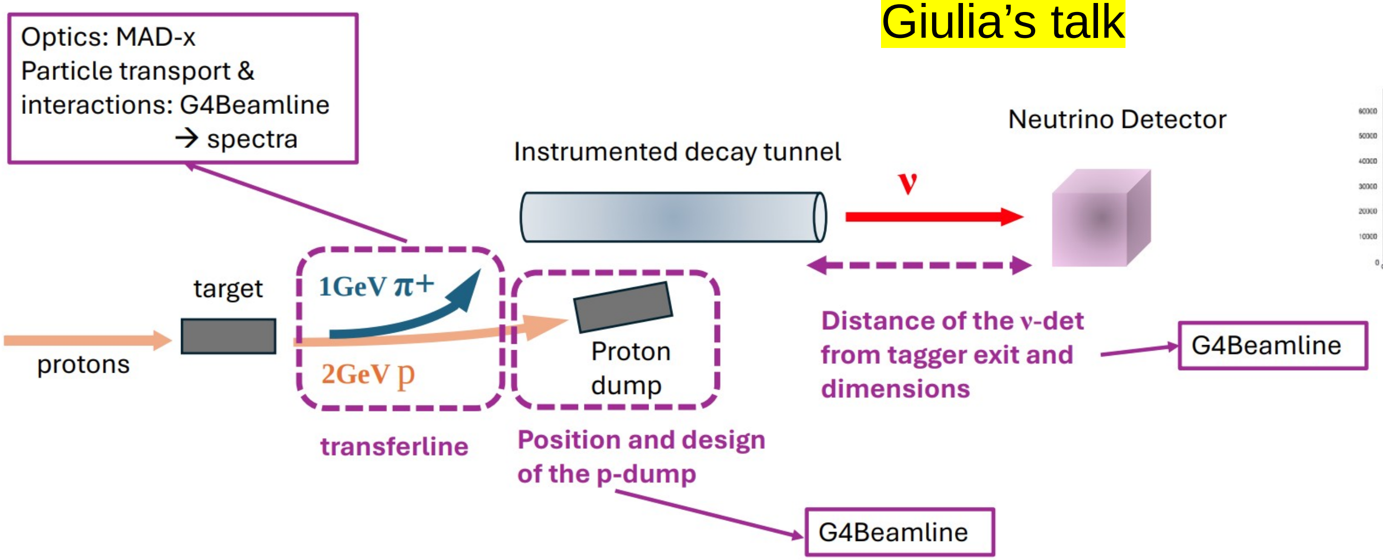
[see also next slides]

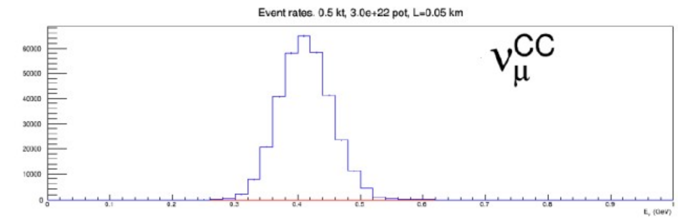
What we discussed

- Preliminary considerations on the beamline and conceptual design (*G. Brunetti*)
- New studies on the tunnel instrumentation (*A. Branca*)
- A candidate technology for the tunnel instrumentation: Picosec MM (*A. Kallitsopoulou*)

Towards a beamline design

Giulia's talk





With 1 GeV/c ± 10% π → <E$_\nu$> ~ 400 MeV (@ 50 m)

Design of the Beamline – The Optics

We need:

- **Large aperture magnets**: Using as a reference CERN quad w/ 20 cm apertures and length=1m
- Separation from primary protons → use bending dipoles, also w/ aperture of 20 cm
  - ENUBET case: we used 2 DIPOLES bending in the same direction to have a large angle separation from primary protons TO SUPPRESS NEUTRINOS at the neutrino detector coming FROM THE PROTON DUMP -- BUT we had 450 GeV protons and 8.5 GeV K+
  - ESSnuSB+:
    - **we need to separate 1GeV pions from 2GeV protons → we need enough drift distance after a dipole**
    - **consider a tunnel with 50 cm radius (VS 1m radius in ENUBET)**

→ Started exploring a design with two dipoles w/ opposite bending:

- First one for separation
- Second one to have a collimated parallel beam
- Studying optimal drift distance after 1st dipole
- Using 50 cm separation between the other elements to **keep the transferline as short as possible**

To maximize the collection of large angle π from the target

To measure low angle muons (max 40 mrad)

Minimize early decays

Conceptual design

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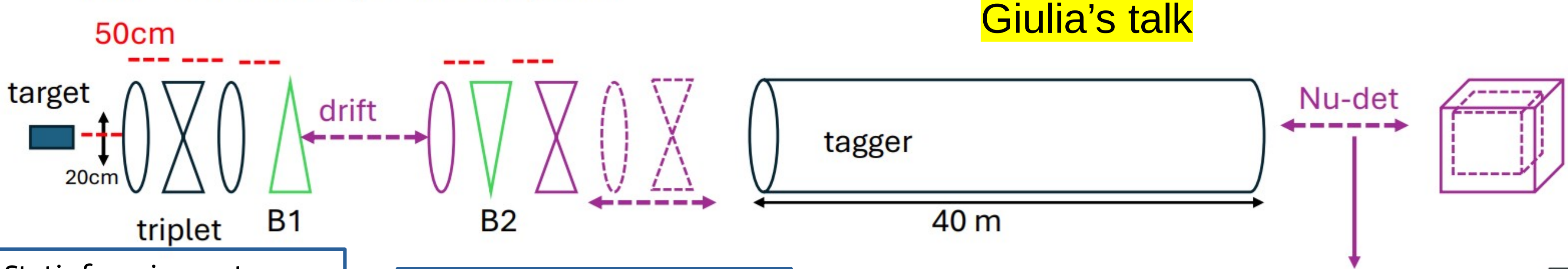
Goal: transport O(10^{-4}) π/pot

•**MAD-x** Tentatively something like:

Giulia's talk



Static focusing system
(no need for an accumulator)

Optimize drift for proton separation and number of quadrupoles before tunnel for a well contained beam

Neutrino spectra w/ G4BL VirtualDetectors: will try **different distances** from the tagger exit and **different front-face sizes**

ENUBET
$6 \times 6 m^2$
50 m from tagger exit

Integrate te findings of WP5 on the LEMMON-D design

Next steps

- Come up with a first acceptable optics design
- Implementation on **G4Beamline** with collimators, shielding and p-dump
  → Optimization in terms of pion yield, bkg at tunnel, neutrino bkg at detector
- Re-iterate the procedure with improved optics towards the final satisfactory design
- Beamline implementation in **FLUKA** for dose assessment on magnets and tunnel instrumentation

The work should get momentum in the next months from the recent completion of hiring procedures:

A. Scanu (PhD student – MIB)

D. D'Ago (PostDoc – INFN-PD)

New tunnel instrumentation design

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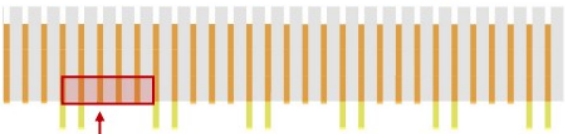
Antonio's talk

Assuming:
- 8.3×10^{14} pot/spill in 2.86 ms
- 1 GeV/c ± 10% pions; 10^{-4} π/pot

Calorimetric technology



Calorimetric module
1x1 cm² / 5.5 cm length

→ 3 radial layers

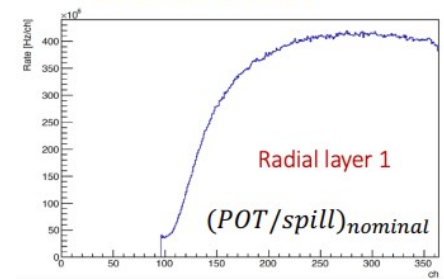
MicroMegas technology

Picosec-MicroMegas Pads
1x1 cm² / 1 cm thick

Iron absorbers
10 cm thick

→ 5 radial layers

Peak @ ~400 MHz/ch

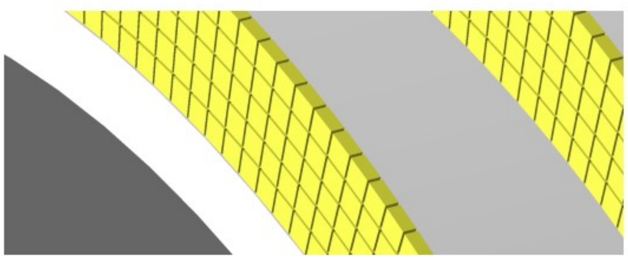


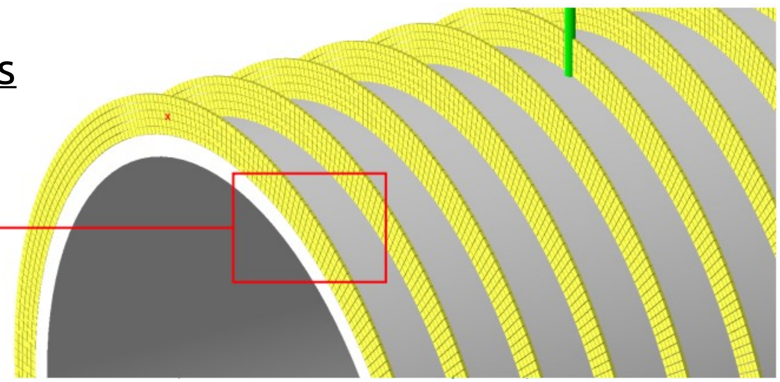
No need for calorimetric tech à la ENUBET (no e⁺, only muons) → Different setup with tracking stations every 10 cm (5 radial layers)

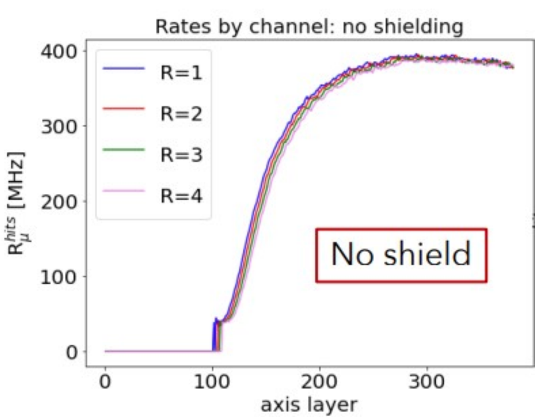
Too large pile-up

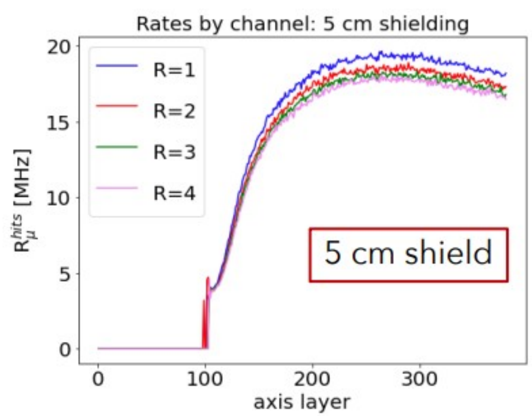
New scheme: iron shielding to filter out part of the muons

- 50 cm tunnel radius
- 1 cm² pads
- 5 mm thickness
- 5 radial layers
- 10 cm spacing in longitudinal direction









- Factor 20 reduction in muon hit rate
- To make it compatible with the use of micromegas and to be safe in terms of pile-up in μ reco, **2-3 Mhz/ch** is desirable

Need to reduce the spill intensity to 10^{14} p/spill

Impact of the Fe-shielding on monitoring (I)

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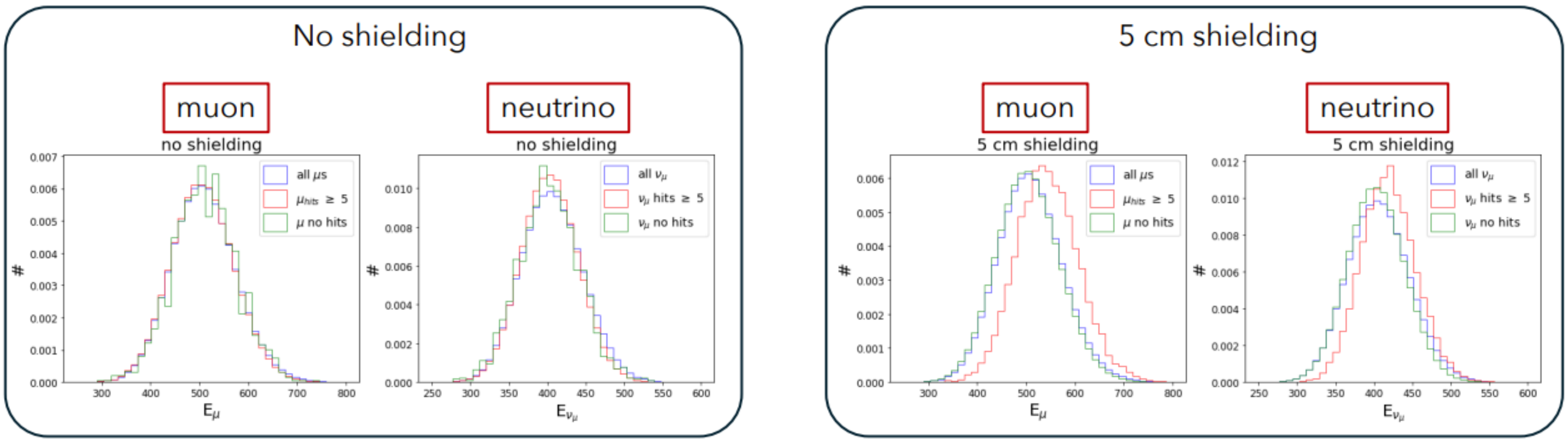
Antonio's talk

Energy distributions

Energy distributions of ν_μ and μ for events where the neutrino crosses the detector (normalized distributions):

- Blue: all muons (w/ and w/o hits at detector);
- Red: only muons w/ at least 5 hits at detector;
- Green: only muons w/o hits at detector;

Assuming we need at least 5 hits to reconstruct the muon



The pre-scale on muons reaching the instrumentation determined by the shielding seems to not introduce a significant bias on the spectrum of monitored neutrinos

Impact of the Fe-shielding on monitoring (II)

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What is important in order to determine the systematic uncertainty on the neutrino flux (and in particular the dominant one coming from hadro-production) is the coverage of the pion phase space

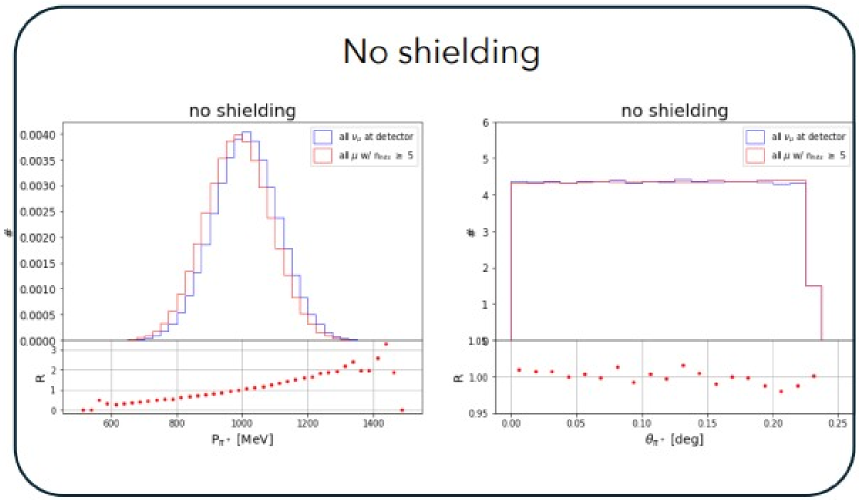
Antonio's talk

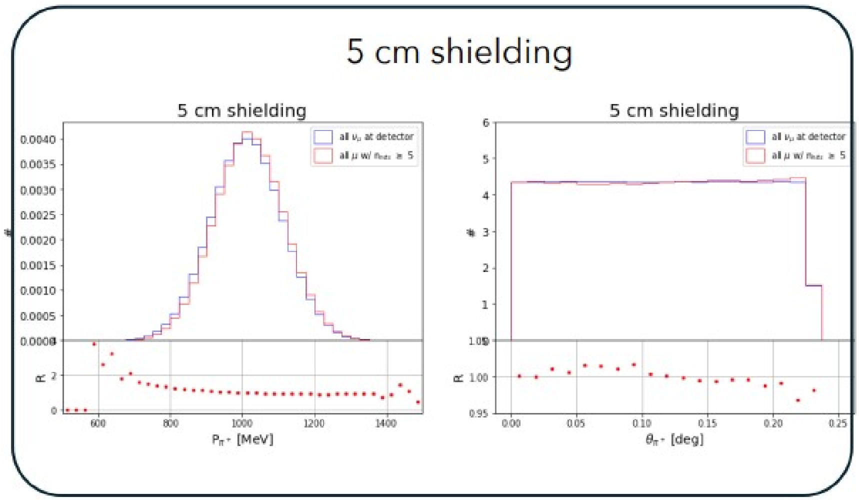
Pions phase space

Distributions of pions energy and angle (normalized distributions) for events where:

- Blue: ν_μ crosses the detector (mu can do everything);
- Red: muons w/ at least 5 hits at detector (ν_μ can do everything);
- Ratio R: Blue/Red;

Assuming we need at least 5 hits to reconstruct the muon





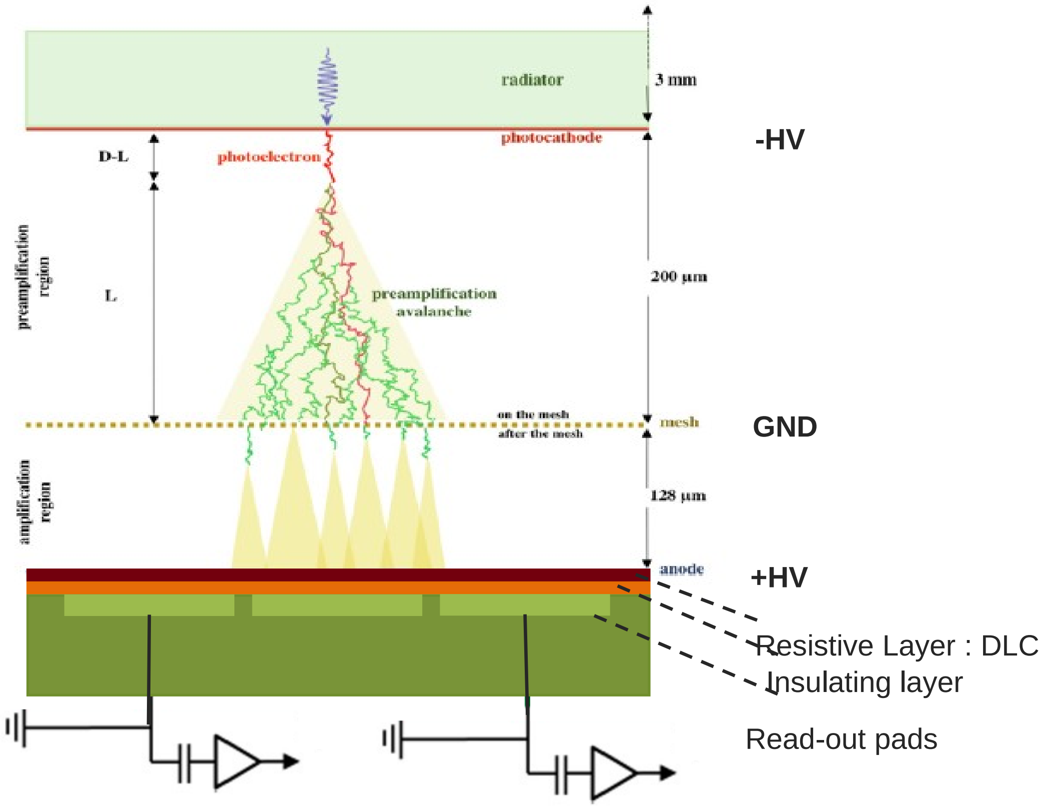
We are able to sample all the pion phase space related to neutrinos hitting the detector, even using a 5 cm shield thickness

A possible candidate: PICOSEC MM

Alexandra's talk

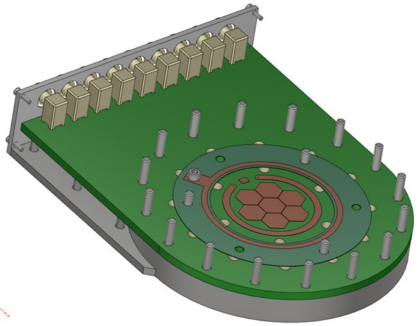
- Micromegas with Cherenkov radiator to push time resolution at the picosecond level

- New resistive prototypes with a DLC insulating layer on the anode:
  → Protection against destructive effects of discharges
  → Provide a stable operation in harmful environment (e.g. pions)



Testbeam activities

Alexandra's talk



Multipad prototype
(7, 1 cm^2 pads)

- Particle Beams @ CERN SPS H4
  - Electrons 30GeV
  - Calculated rate ~1MH/cm2

In the ballpark expected in the instrumented decay tunnel!

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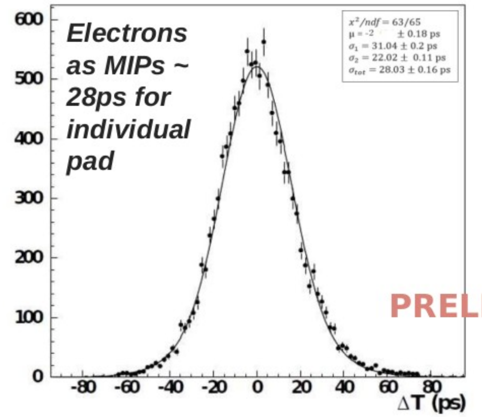

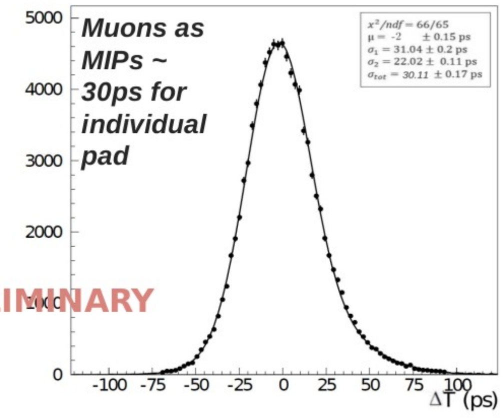

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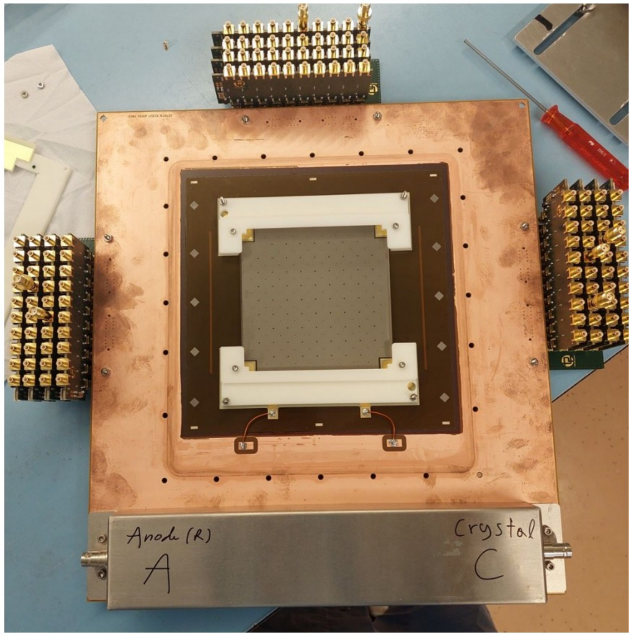
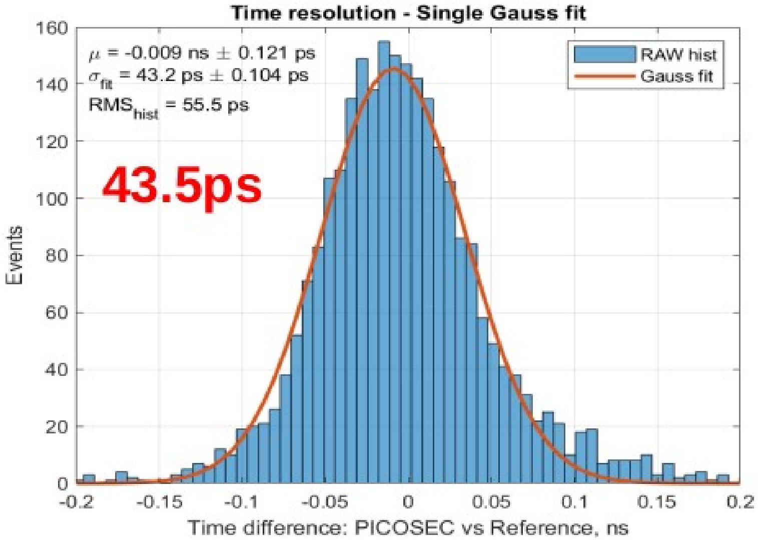


96-pad prototype
(1 cm^2 pads)

Advantages:

- Low material budget on the detector
- Allow the fabrication of large flat boards

July testbeam @ CERN



Outlook

- Activities of WP6 in full swing, now that hiring procedures are completed
- Starting to design a realistic beamline with a full-fledged simulation
- Setup of the simulation framework of the instrumented decay tunnel completed. Tuning of the technology and of the reconstruction algorithm with the realistic pion beam (and backgrounds) from the beamline simulation
- Deadlines for next milestones and deliverables within reach:
  - D 6.1: “Design of the transfer line” [31/12/2024]
  - MS 12: “MC simulation framework for the tunnel instrumentation is set up” [31/12/2024]

Important item to discuss in the next months:

How to get a low intensity spill (10^{14} p/spill) from the ESS LINAC without interfering with the neutron science program