The Instrumented decay tunnel of the ENUBET neutrino beam

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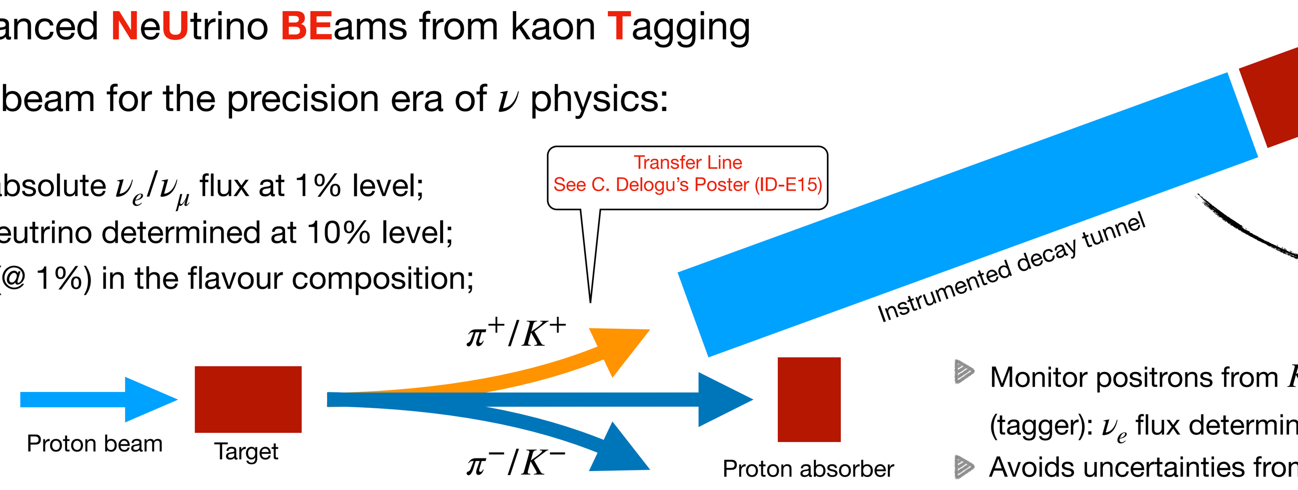
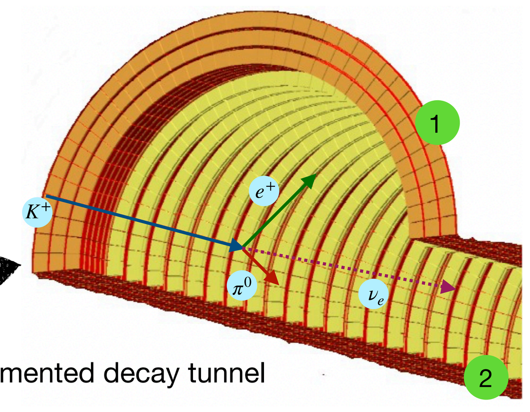
ENUBET: **E**nhanced **N**e**U**trino **BE**ams from kaon **T**agging

A narrow-band beam for the precision era of ν physics:

- Knowledge of absolute ν_e/ν_μ flux at 1% level;
- Energy of the neutrino determined at 10% level;
- High precision (@ 1%) in the flavour composition;





- Monitor positrons from K_{e3} decays with a fully instrumented decay tunnel (tagger): ν_e flux determination from e^+ counting;
- Avoids uncertainties from Protons-on-Target (POT), hadron-production, beam line efficiency;

1 Calorimeter

- Sampling calorimeter: plastic scintillator + Iron absorbers;
- Three radial layers of **U**ltra **C**ompact **M**odules (**UCM**: $3 \times 3 \times 10\ cm^3 - 4.3X_0$) with longitudinal segmentation;
- light collection/readout: WLS fibers & SiPM;

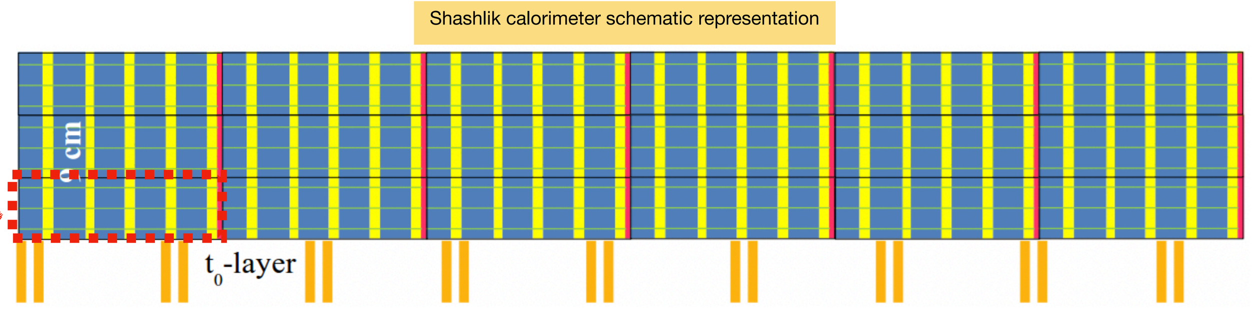
Allows $e^+/\pi^+/\mu$ separation

2 Photon Veto

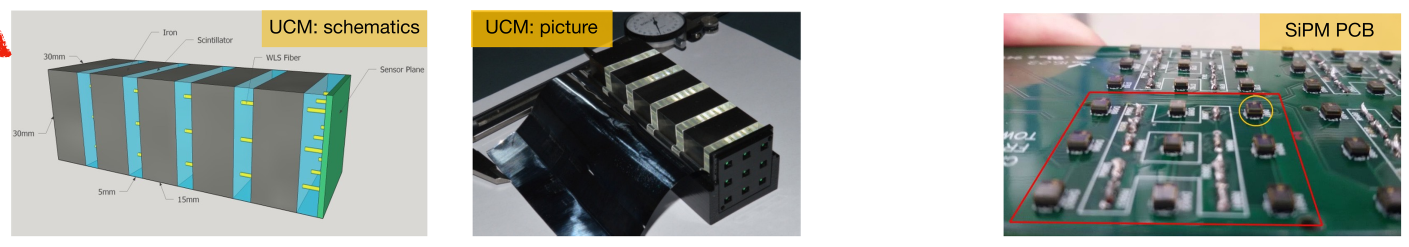
- Plastic scintillator;
- $3 \times 3\ cm^2$ tiles arranged in doublets forming inner rings;

Allows π^0 rejection

Baseline for the calorimeter: shashlik technique



Shashlik: WLS fibers perpendicularly crossing the absorber/scintillator tiles



Layout of the UCM:

- Transverse size of $3 \times 3\ cm^2$;
- Longitudinal size $10\ cm\ (4.3X_0)$;
- Light collection: 9 WLS fibers (one/cm^2) coupled to 9 SiPM mounted on PCB (sensor plane);

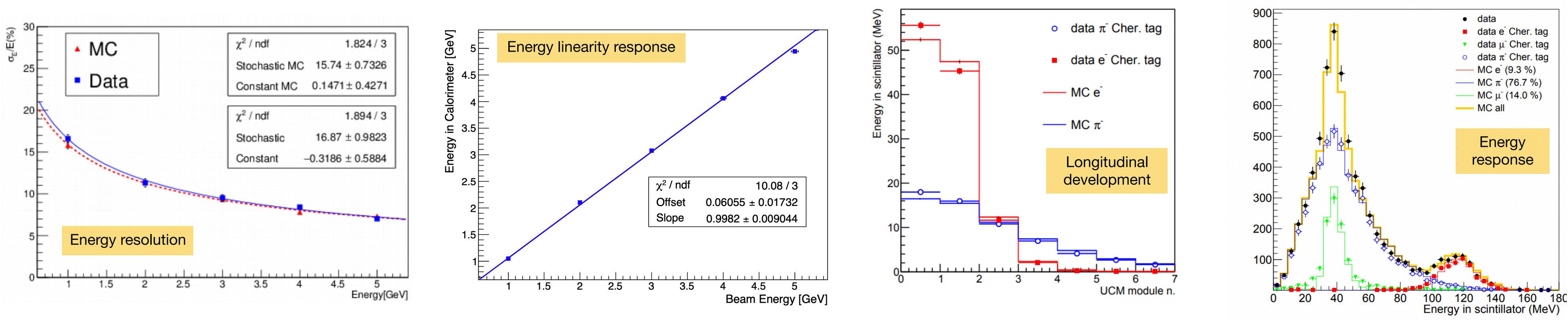
- Sampling calorimeter: 5x(Absorber + Scintillator);
- Absorber: Fe-15 mm;
- Plastic scintillator: EJ200, TiO2 painting;
- Y11 & BCF92 WLS fibers;

PCB for the SiPM

- SiPM soldered to PCBs;
- Highlighted by the red box: 9 SiPM used to readout a single UCM;
- Highlighted by the yellow circle: a single SiPM sensor (FBK $20\ \mu m$ cell size);

Shashlik prototypes tested @ CERN (PS-T9)

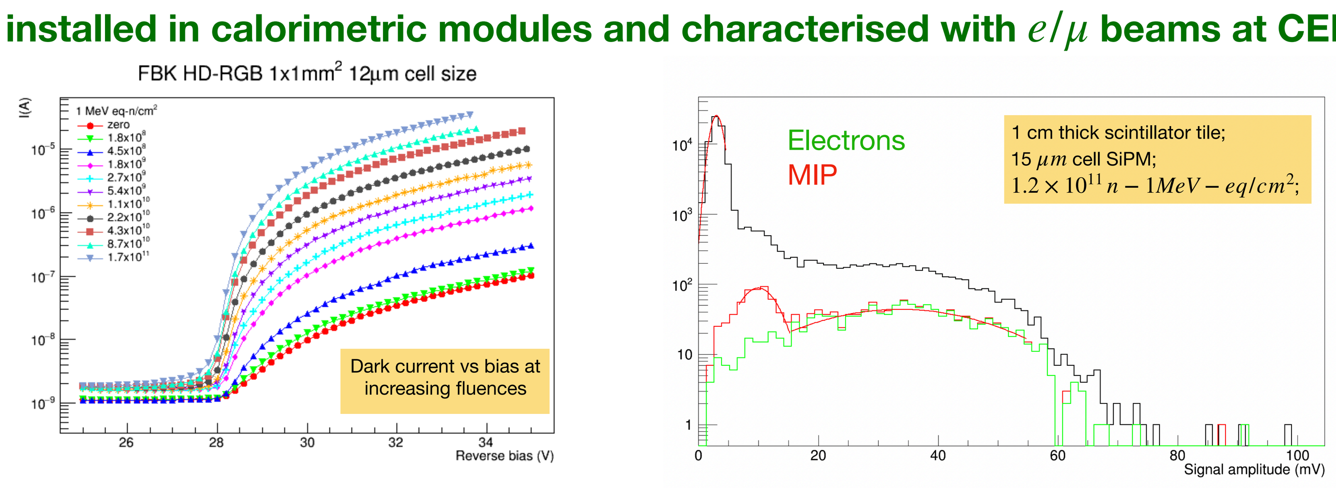
Result of the tests performed on the prototypes: response to e^+, π^+ and MIP



- Electromagnetic energy resolution: $\sim 17\%/\sqrt{E\ (GeV)}$;
- Deviations from linearity of the energy response: $< 3\%$ **in the** $1-5\ GeV$ **range**;
- Measurements repeated at different beam tilt angle w.r.t. direction perpendicular to calorimeter (0 to 200 mrad): **no significant difference found**;
- Difference in longitudinal profile for e/π allows good particle separation (mis-identification $< 3\%$): **reproduced by MC within 10% for π and 5% for e**;
- Energy response of the detector prototype to $e/\pi/\mu$ shows a **good agreement with MC simulation** (equalizing UCM response with MIPs): non uniformities dominated by fibers-to-SiPM mechanical coupling;

SiPM irradiation tests

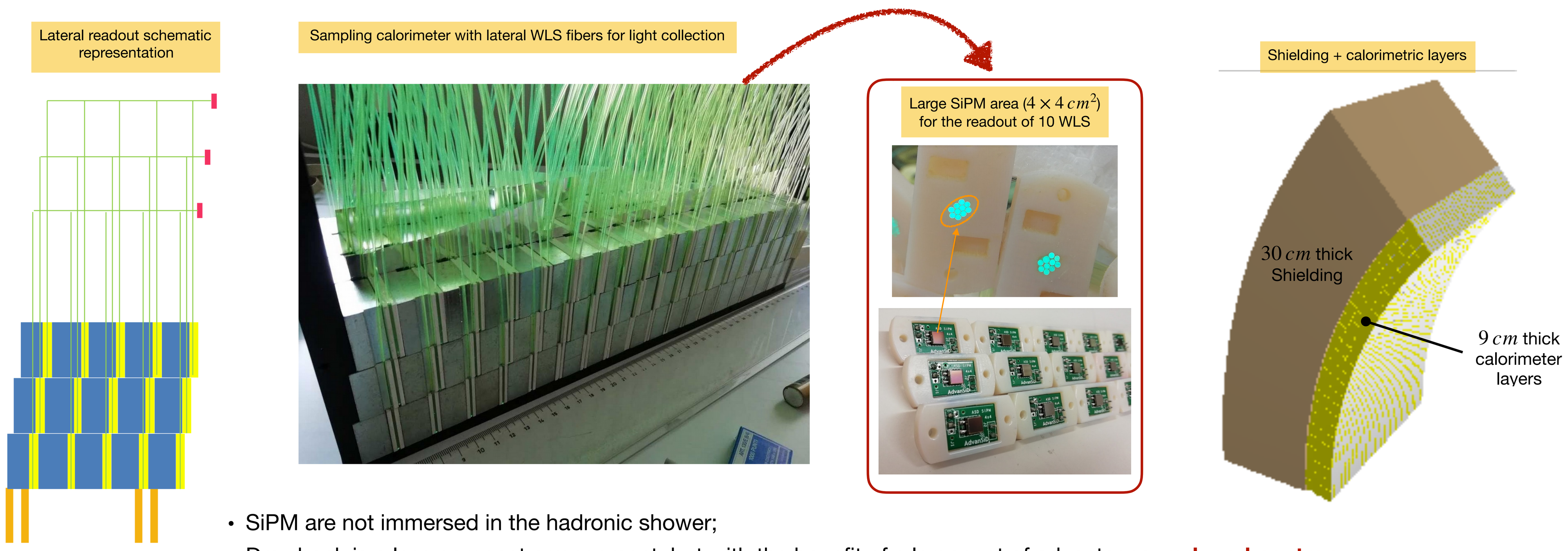
Irradiation tests with neutrons performed @ LNL. Irradiated SiPM have been installed in calorimetric modules and characterised with e/μ beams at CERN:



- Minor changes in the breakdown voltage as a function of neutron fluence;
- Dark current after breakdown increases by more than two order of magnitudes at the fluence expected for the entire lifetime of the experiment ($\sim 10^{11}\ n/cm^2$);
- Even with the maximum neutron fluence expected for the experiment lifetime, MIP signals remain well separated from dark noise peak if SiPM cell size and scintillator thickness are properly chosen;

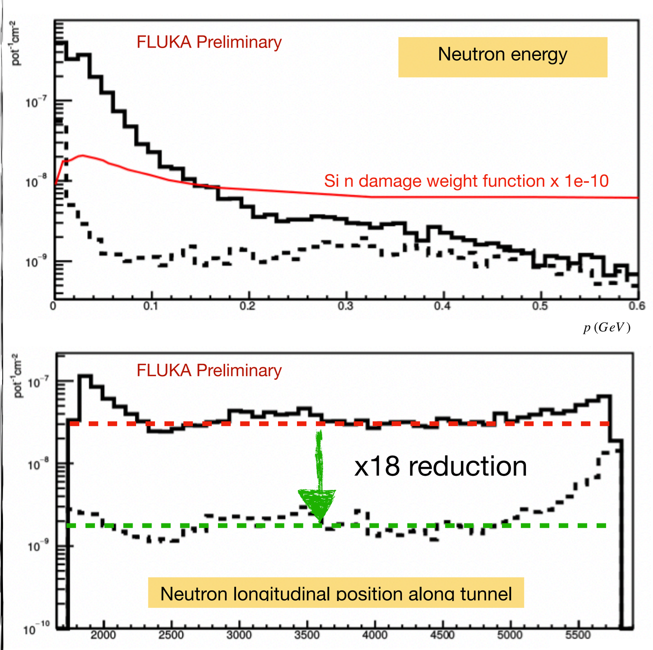
Overcome SiPM irradiation ageing: lateral readout option

Light collected from scintillator sides and bundled to a single SiPM reading 10 fibers (1 UCM)

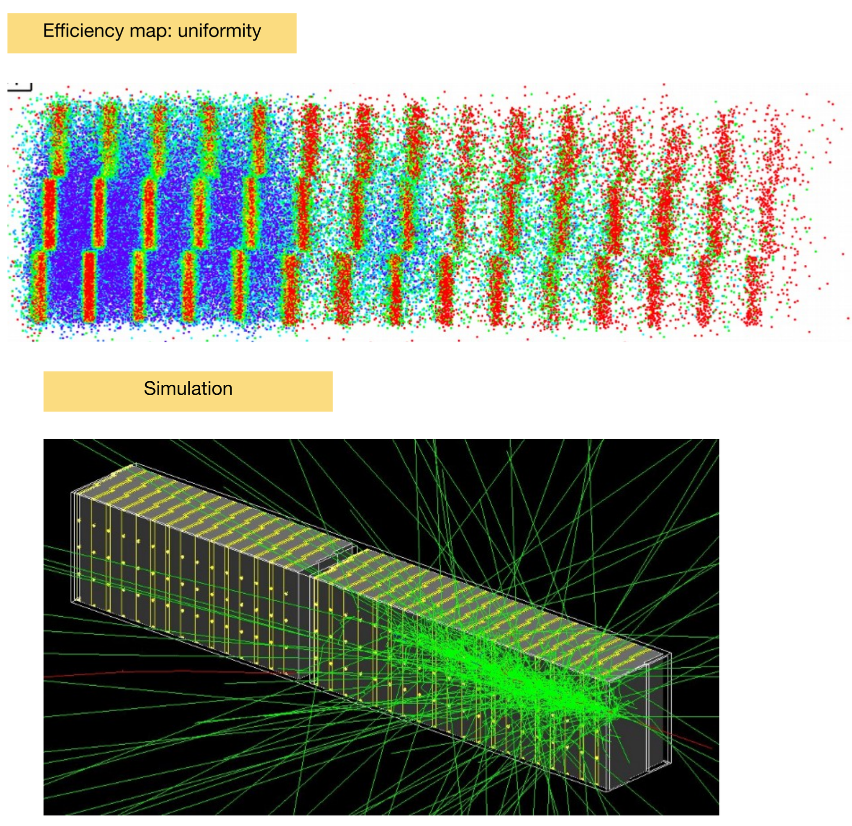


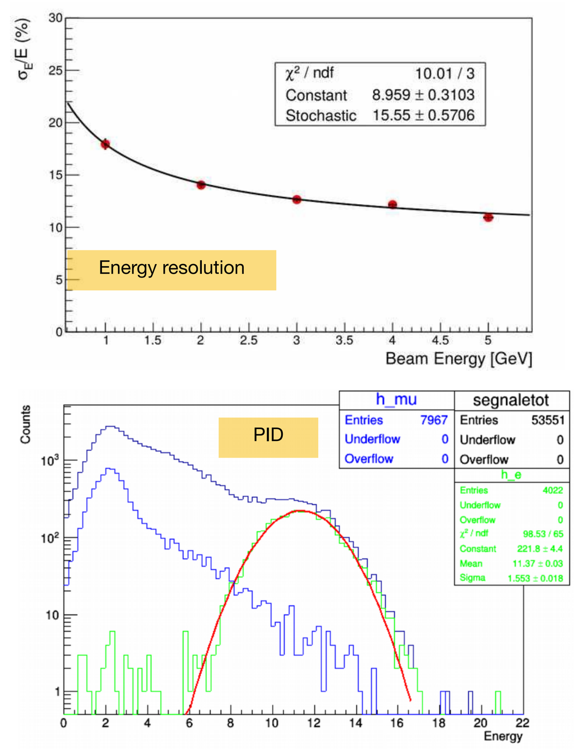
- SiPM are not immersed in the hadronic shower;
- Drawback is a less compact arrangement, but with the benefit of a larger set of advantages: **reduced neutron damage**, **better accessibility**, **possibility of replacement**, **better reproducibility of WLS-SiPM optical coupling**;

Preliminary results: lateral readout tests & simulation



- 30 cm of borated polyethylene in front of SiPM;
- FLUKA full simulation - 400 GeV protons;
- Very good suppression: factor of ~18 reduction (average over spectrum);

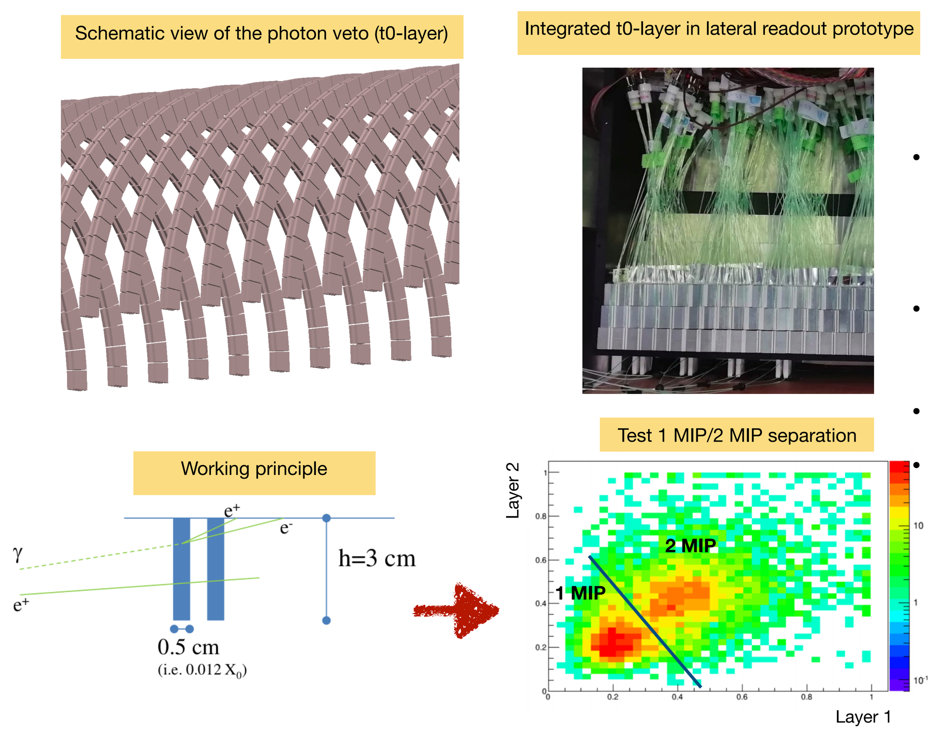




- Good signal amplitude;
- Checking the impact of light connection uniformity and reproducibility off WLS-SiPM optical match: **in progress**;

Photon veto

Test beam @ CERN-PS T9 line 2016-2018 to establish γ/e discrimination and timing capabilities

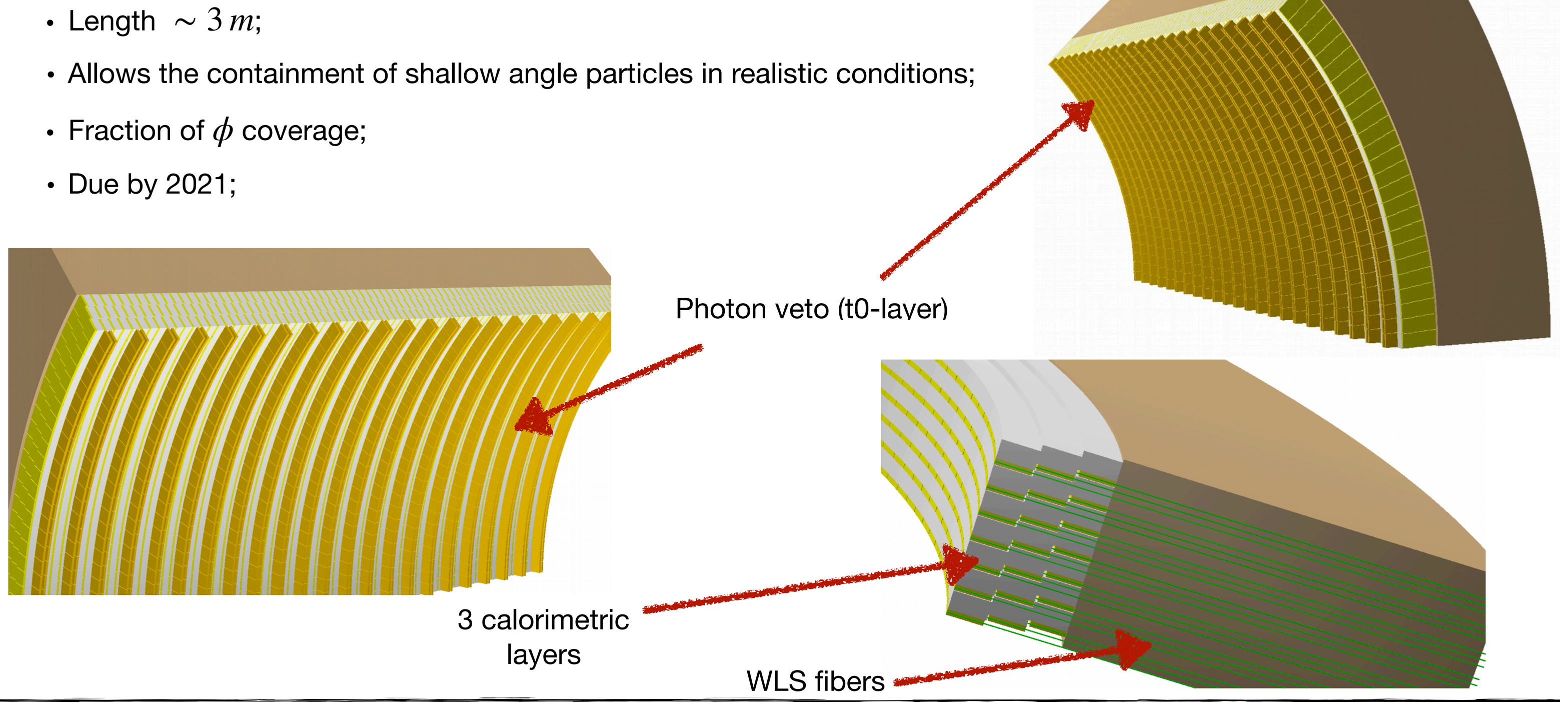


- t0-layer setup: scintillator tails pair ($3 \times 3 \times 0.5\ cm^3$) + WLS fiber + SiPM;
- Exploit charge exchange reaction $\pi^- p \rightarrow n\pi^0 (\rightarrow \gamma\gamma)$;
- Light collection efficiency > 95%;
- Time resolution: $\sigma_t \sim 400\ ps$;

The tagger demonstrator

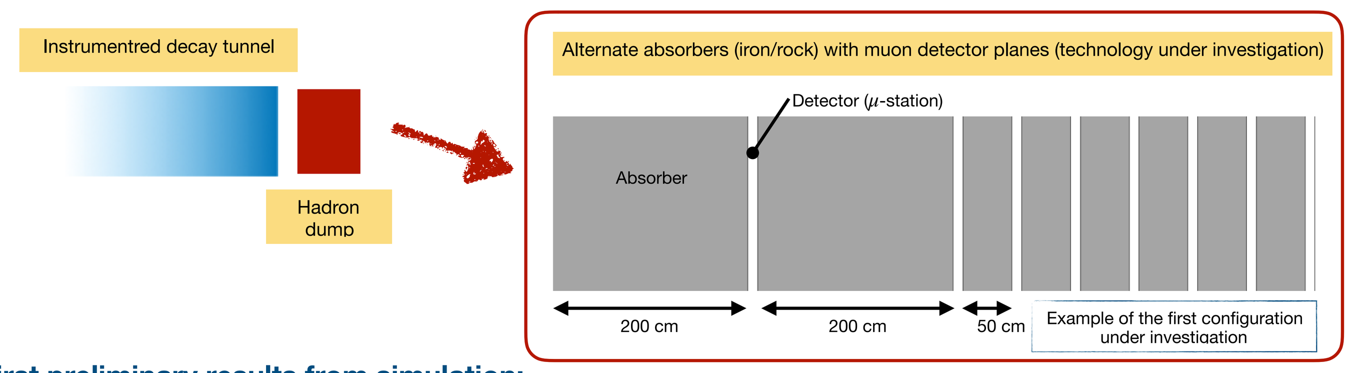
Recognition of ENUBET in the Neutrino Platform as ENUBET/NP06: renovated East Area for the final validation of the demonstrator

- Length $\sim 3\ m$;
- Allows the containment of shallow angle particles in realistic conditions;
- Fraction of ϕ coverage;
- Due by 2021;

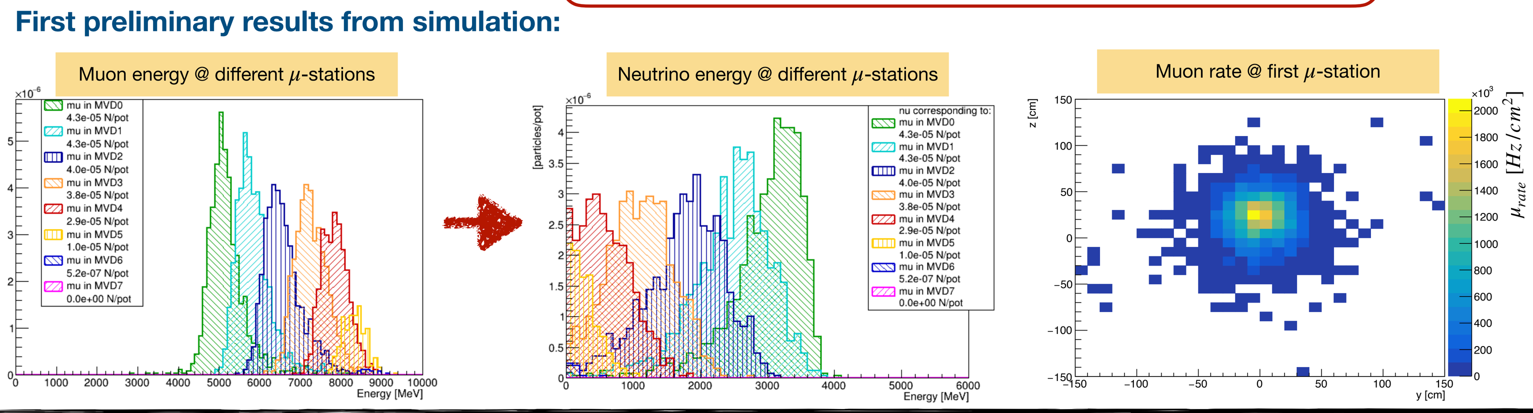


First studies for the development of a muon monitoring system

Use the tagger to constrain the high energy ν_μ spectrum from K^+ decays (in progress), and detectors (μ-stations) following the hadron dump to constrain the low energy ν_μ spectrum from π^+ decays



First preliminary results from simulation:



- Exploit μ^+ from $\pi^+ \rightarrow \mu^+\nu_\mu$ decays within the tunnel as a proxy for a measurement of the ν_μ flux;
- Neutrino and muon from pion decay exit the tunnel without crossing the calorimeter;

Studies in progress:

- Determination of the muon detector technology to employ: estimation of neutron fluence and muon rate;
- Studies of the systematic impact on the neutrino flux: punch-through, absorber non uniformity, detection efficiency, halo muons ….

References

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