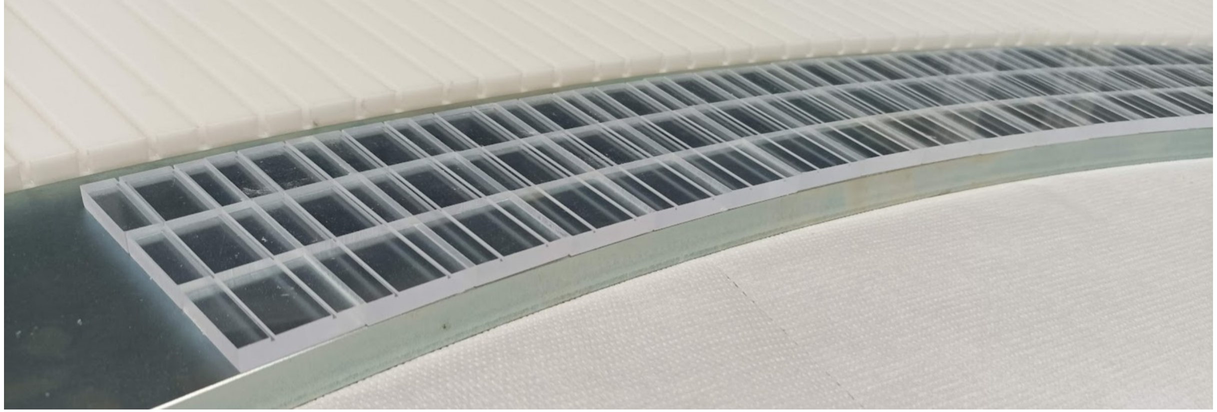
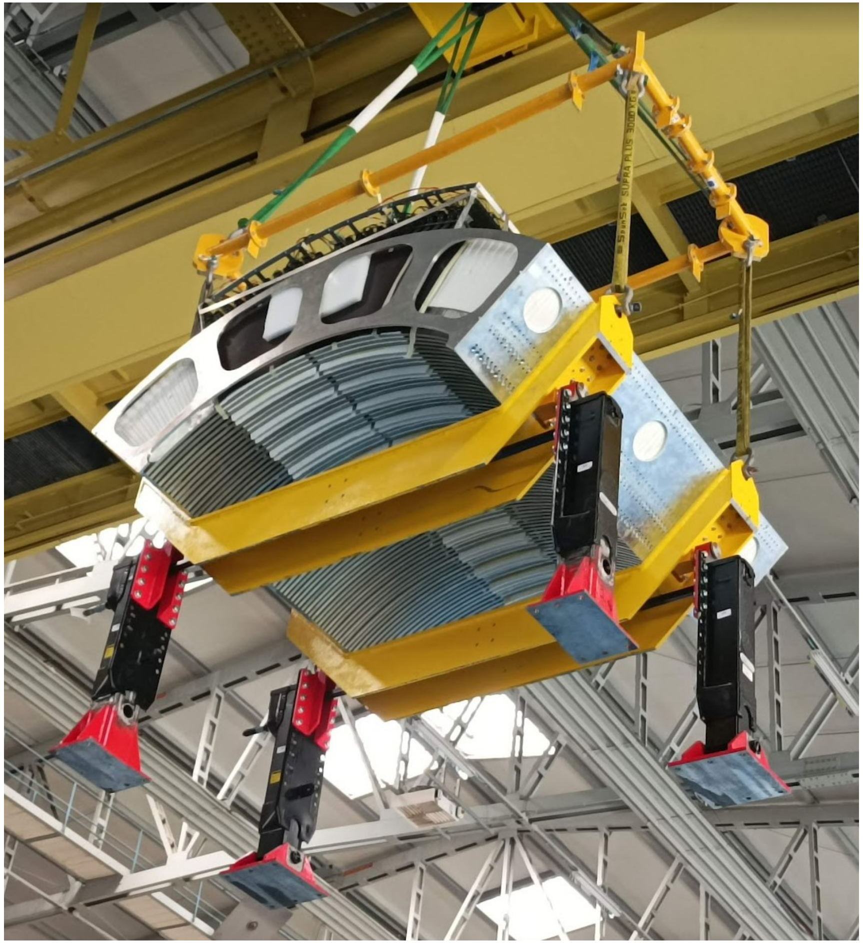
NP06 / ENUBET

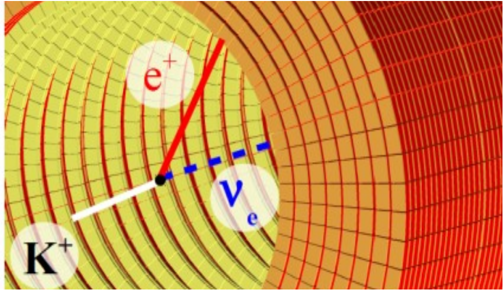
A. Longhin
Padova Univ. and INFN
on behalf of the ENUBET Coll.

NBI 2024, 7/10/2024
Tōkai, Japan





NP06/ENUBET development



- A dedicated short baseline neutrino beam with a 1% precision in ν_e and ν_μ fluxes aimed to a refined near detector
- Reduce the dominant systematics on flux → precise cross section measurements → consolidate the long-baseline program with high quality experimental inputs

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

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

@enubet

ERC project 6/2016- 12/2022

PI: A. Longhin, F. Terranova. Techn. Coord: V. Mascagna

Enhanced **N**e**U**trino **BE**ams from kaon **T**agging ERC-CoG-2015, G.A. 681647, PI A. Longhin, **Padova University, INFN**

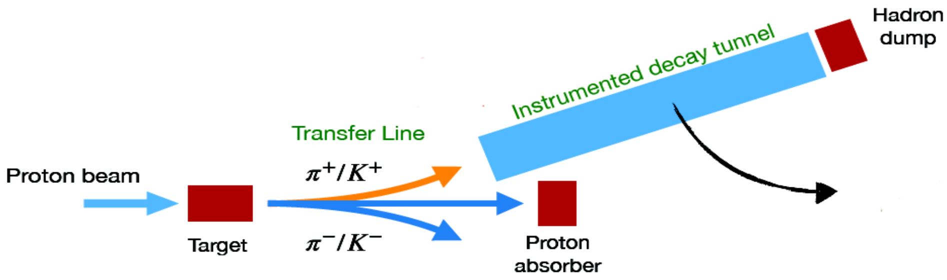
- CERN Neutrino Platform: NP06/ENUBET
- Physics Beyond Colliders

Present collaboration: 74 auth, 17 institutions

- **NP06/ENUBET: a monitored beam at 400 GeV (meas. decay products)**

ENUBET

… the first **"monitored neutrino beam"**:

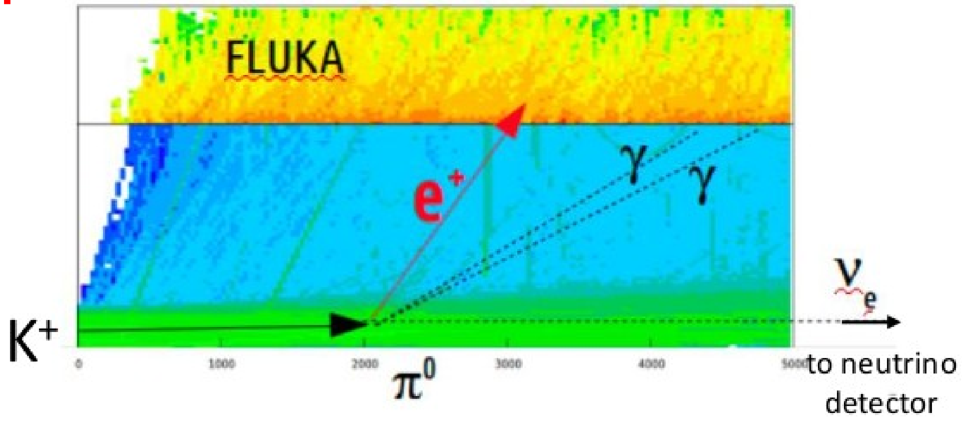


production of neutrino-associated leptons monitored at single particle level in an instrumented decay region

$K^+ \rightarrow e^+ \nu_e \pi^0 \rightarrow$ (large angle) e^+

$K^+ \rightarrow \mu^+ \nu_\mu \pi^0$ or $\rightarrow \mu^+ \nu_\mu \rightarrow$ (large angle) μ^+

- **ν_e and ν_μ flux prediction from e^+/μ^+ rates**



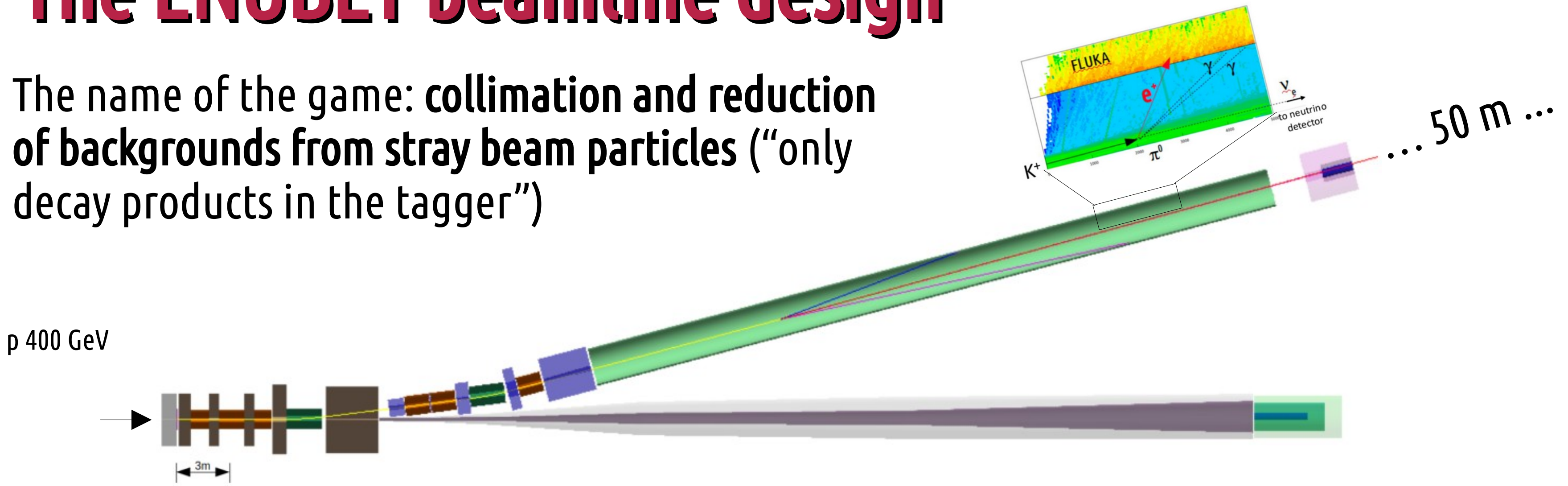
- Needs a **collimated mom-selected hadron beam** → only the decay products hit the tagger
  → manageable rates and irradiation in the detectors
- Needs a **"short" decay region** : ~all ν_e from K, only ~1% ν_e from μ (large flight length)

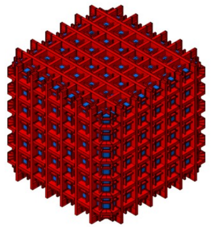
NB: it requires a **specialized beam**, not a "pluggable" technology for existing super-beams (unfortunately!)

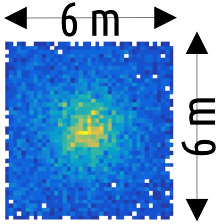
- NP06/ENUBET: a monitored beam at 400 GeV (meas. decay products)
  - **Beamline design and performance**

The ENUBET beamline design

The name of the game: **collimation and reduction of backgrounds from stray beam particles** ("only decay products in the tagger")







- Focuses **8.5 GeV +/- 10%** **mesons** (ν spectrum ROI ~ DUNE)
  - Length: 26 m
  - Tagger length: 40 m
  - Neutrino detector (500 t) 50 m after the hadron dump
  - 14.8° bending angle
- documented in **EPJ-C 83, 964, 2023**

Design and performance of the ENUBET monitored neutrino beam

F. Acerbi[1], I. Angelis[21], L. Bomben[2,3], M. Bonesini[3], F. Bramati[3,4], A. Branca[3,4], C. Brizzolari[3,4], G. Brunetti[3,4], M. Calviani[6], S. Capelli[2,3], S. Carturan[7], M.G. Catanesi[8], S. Cecchini[9], N. Charitonidis[6], F. Cindolo[9], G. Cogo[10], G. Collazuol[5,10], F. Dal Corso[5], C. Delogu[5,10], G. De Rosa[11], A. Falcone[3,4], B. Goddard[6], A. Gola[1], D. Guffanti[3,4], L. Halić[20], F. Iacob[5,10], C. Jollet[16], V. Kain[6], A. Kallitsopoulou[24], B. Kliček[20], Y. Kudenko[13], Ch. Lampoudis[21], M. Laveder[5,10], P. Legou[24], A. Longhin[a,5,10], L. Ludovici[15], E. Lutsenko[2,3], L. Magaletti[8,14], G. Mandrioli[9], S. Marangoni[3,4], A. Margotti[9], V. Mascagna[22,23], N. Mauri[9,18], J. McElwee[16], L. Meazza[3,4], A. Meregaglia[16], M. Mezzetto[5], M. Nessi[6], A. Paoloni[17], M. Pari[5,10], T. Papaevangelou[24], E.G. Parozzi[4], L. Pasqualini[9,18], G. Paternoster[1], L. Patrizii[9], M. Pozzato[9], M. Prest[2,3], F. Pupilli[5], E. Radicioni[8], A.C. Ruggeri[11], G. Saibene[2,3], D. Sampsonidis[21], C. Scian[10], G. Sirri[9], M. Stipčević[20], M. Tenti[9], F. Terranova[3,4], M. Torti[3,4], S.E. Tzamarias[21], E. Vallazza[3], F. Velotti[6], L. Votano[17]

https://arxiv.org/pdf/2308.09402.pdf

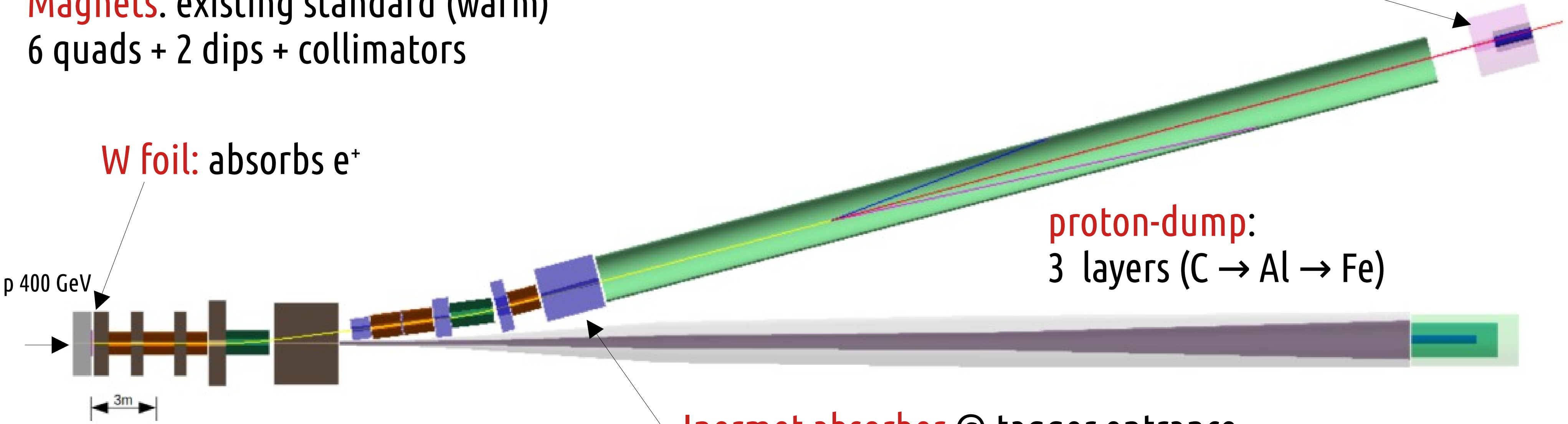
https://link.springer.com/article/10.1140/epjc/s10052-023-12116-3

… a closer look

hadron-dump: ~
optimized to reduce back-scattering in the tunnel & fraction of not-monitored flux

Magnets: existing standard (warm)
6 quads + 2 dips + collimators

W foil: absorbs e^+



proton-dump:
3 layers (C → Al → Fe)

Inermet absorber @ tagger entrance
with conical channel

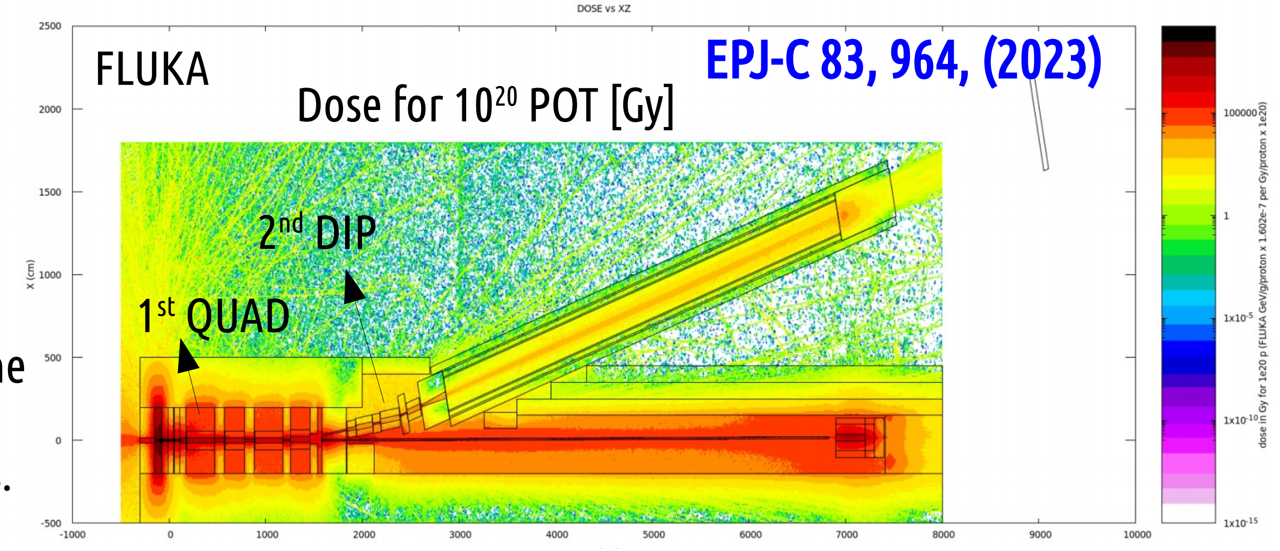
Target: graphite L = 70 cm, r = 3 cm

Simulation: optics optimization (TRANSPORT). Design: G4beamline.
Irradiation (FLUKA). Systematics (GEANT4, fully parametric, access to particle history).

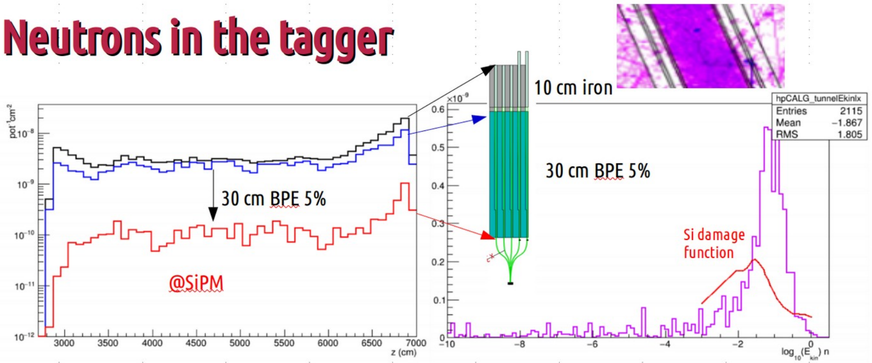
Irradiation levels

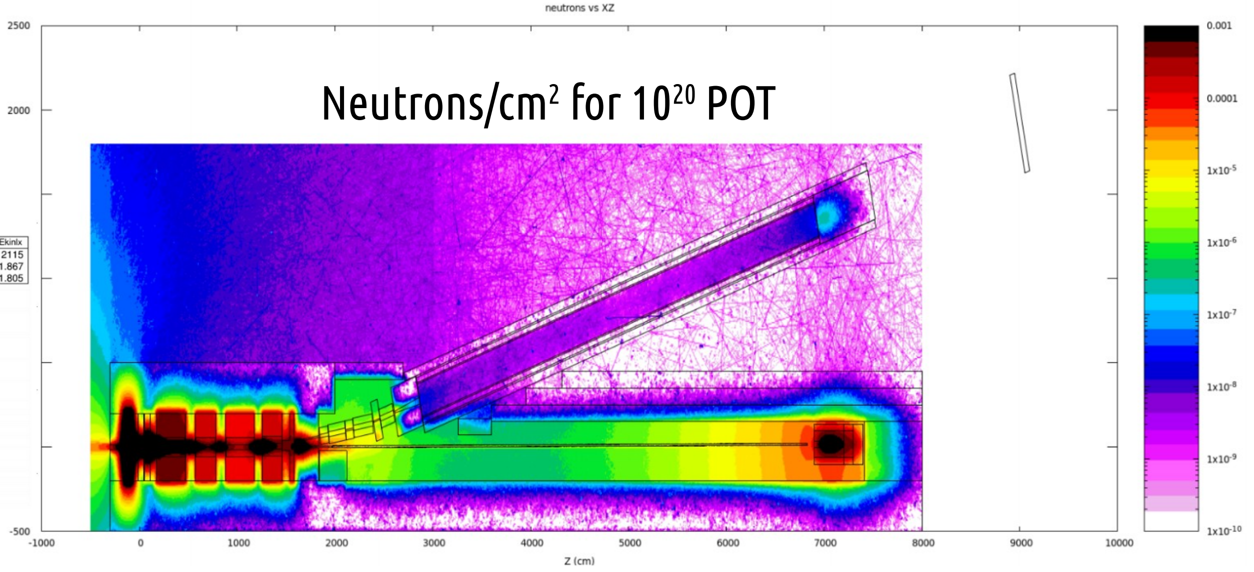
Dose is sustainable by magnets even in the hottest regions (<300 kGy/10^{20} pot).

Neutrons simulations guided the design of the instrumentation → 30 cm of Borated PE (5%) added to protect the Silicon Photomultipliers. Good lifetime (7e9 n/cm^2/10^{20} pot). Accessible eventually.



Neutrons in the tagger



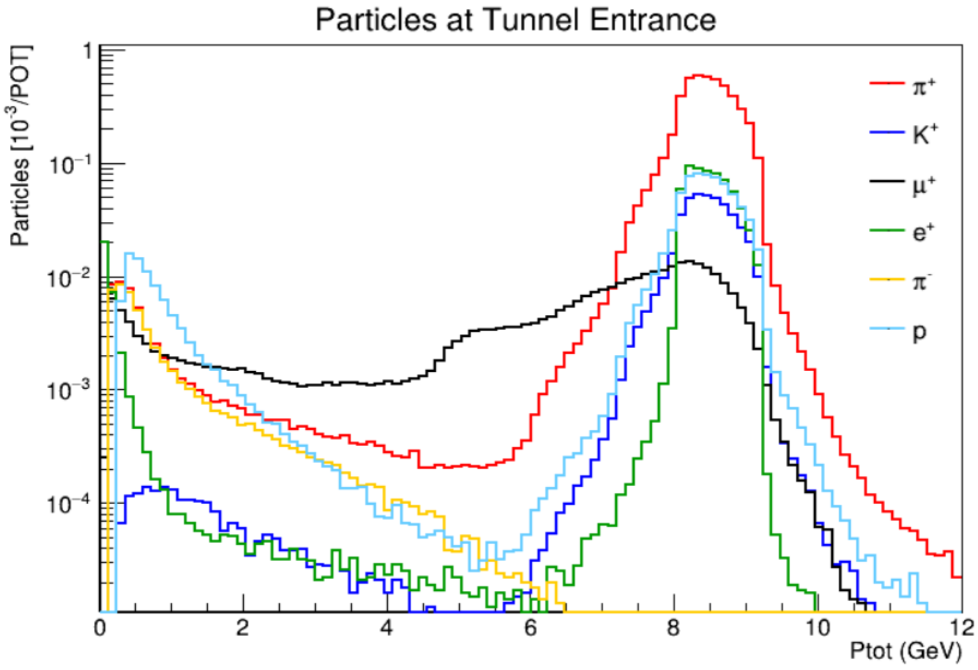


Particle budget and rates

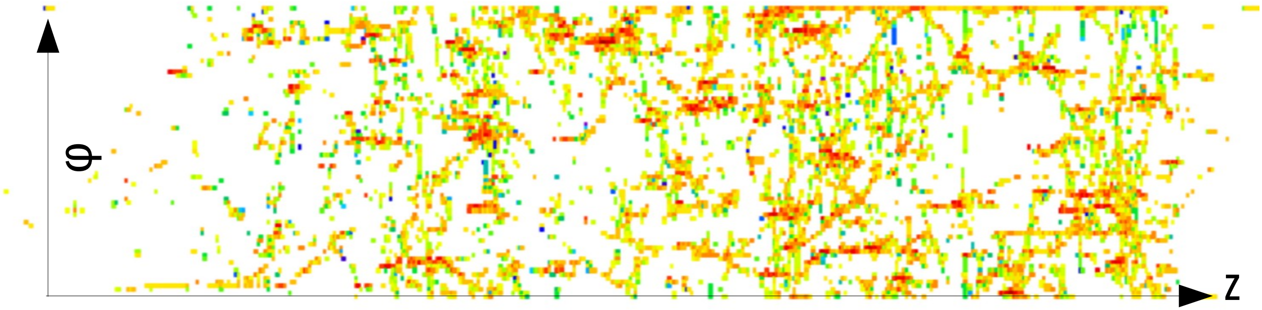
Entering the tagger:
$4.6 \times 10^{-3}\ \pi^{+}$/pot
$0.4 \times 10^{-3}\ K^{+}$/pot

The hottest regions of the tagger see ~ 500 kHz/cm^2 with 2.5×10^{13} pot/2.4 s (slow extraction)
Pile-up mostly non critical but has to be treated.

→ the detector has to be fast enough, radiation hard, cost-effective (large area)



Hit map for e^+ in a few ns



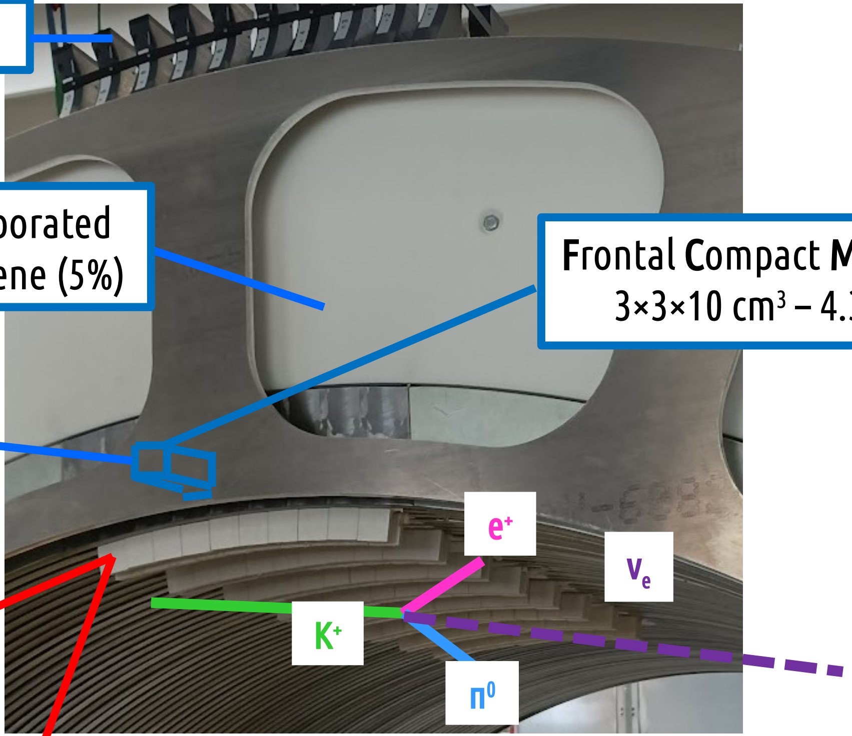
- NP06/ENUBET: a monitored beam at 400 GeV (meas. decay products)
    - Beamline design and performance
    - **Lepton event-by-event reconstruction**

The lepton tagger

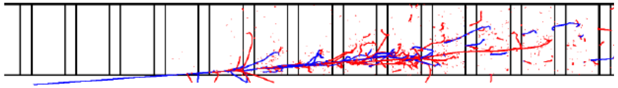
Light r/o (SiPM)

30 cm of borated polyethylene (5%)

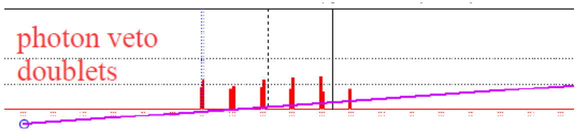
Frontal Compact Module
$3\times3\times10$ cm^3 – 4.3 X_0

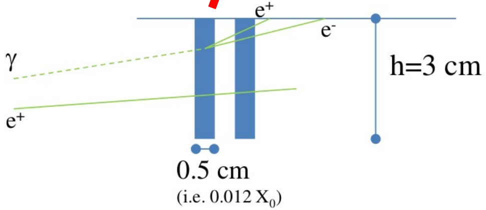


Calorimeter
Longitudinal segmentation
Plastic scintillator + Iron absorbers
Integrated light readout with SiPM
→ $e^+/\pi^\pm/\mu$ separation



Integrated photon veto
Plastic scintillators rings of 3×3 cm^2 pads
→ π^0 rejection





e^+ (signal) topology

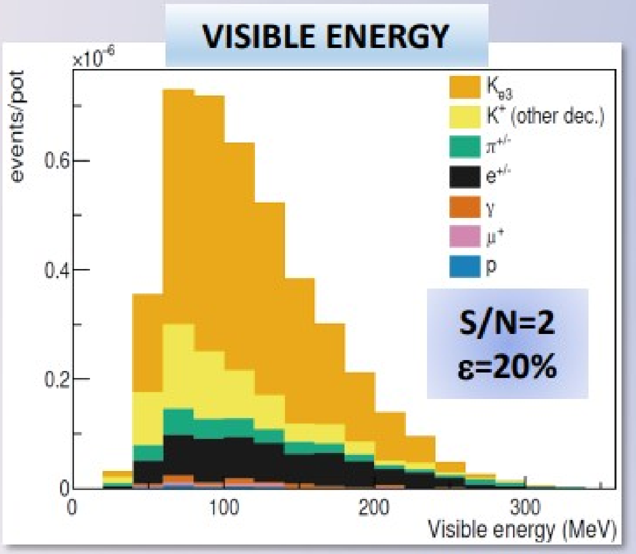
π^0 (background) topology

π^+ (background) topology

Lepton event by event reconstruction

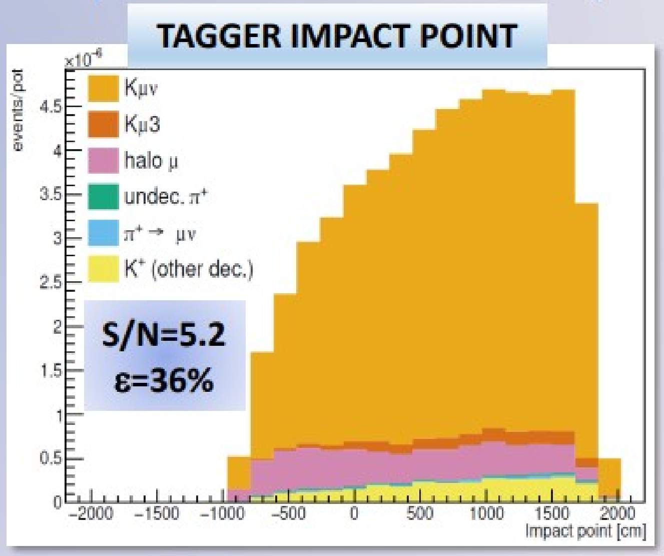
GEANT4 simulation. Event building: clustering of cells in space and time (accounting for **pile-up**) → PID with a Multilayer Perceptron

K_{e3} positrons → constrain ν_e



Efficiency ~half geometrical

$K_{\mu 2}$ muons → constrain ν_μ



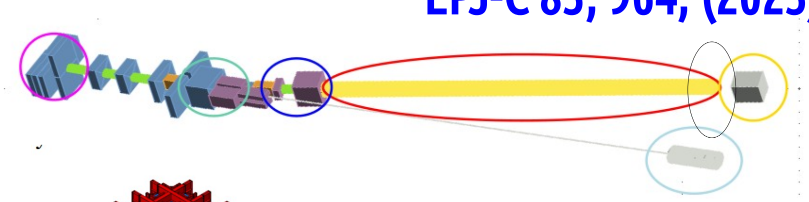
Efficiency ~half geometrical

See EPJ C 83 (2023) 964

- NP06/ENUBET: a monitored beam at 400 GeV (meas. decay products)
  - Beamline design and performance
  - Lepton event-by-event reconstruction
  - **Achievable ν^{CC} event spectra/rates and systematics reduction**

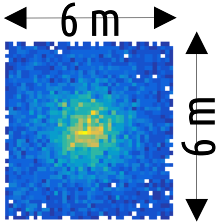
$\nu_{\mu/e}$ CC spectra at detector

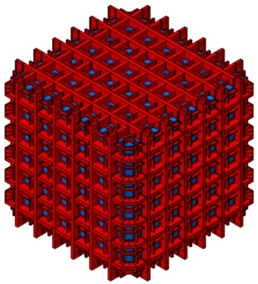
EPJ-C 83, 964, (2023)



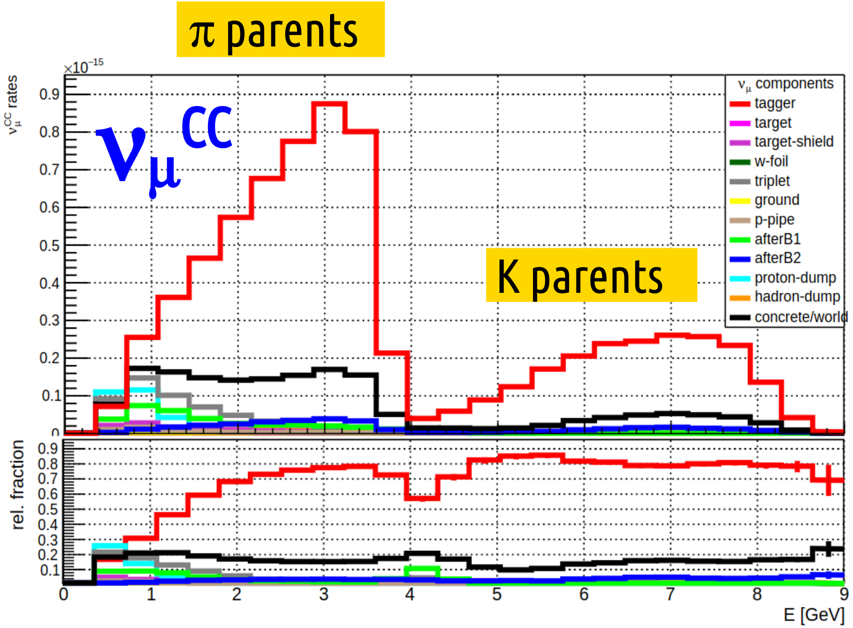
500t @ 50 m after the hadron dump
@ 400 GeV → **0.7 M$\boldsymbol{\nu}_\mu$**^{CC} with 1e20 POT

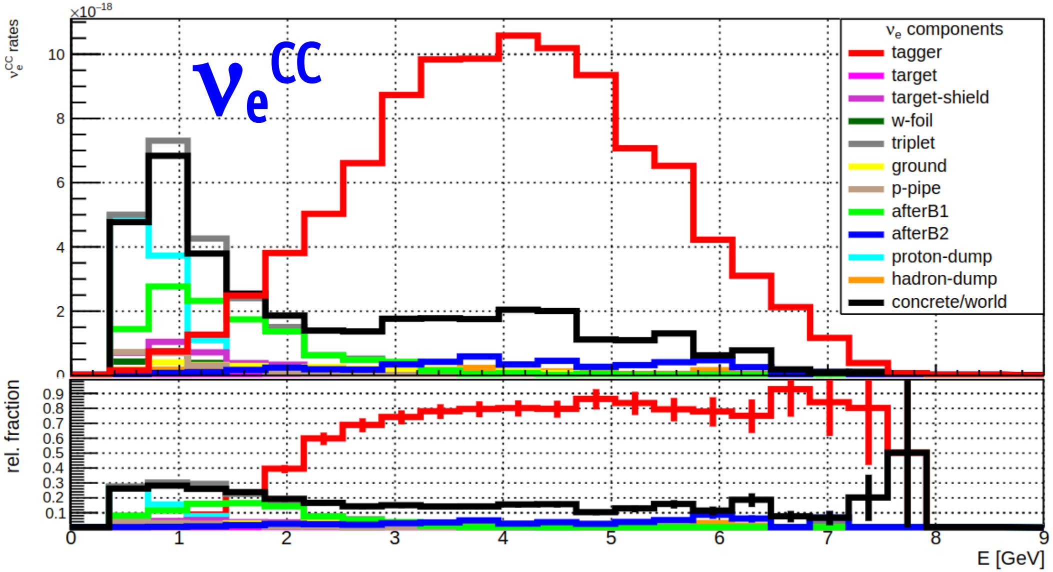
→ **10000 $\boldsymbol{\nu}_e$**^{CC} with ~1e20 POT





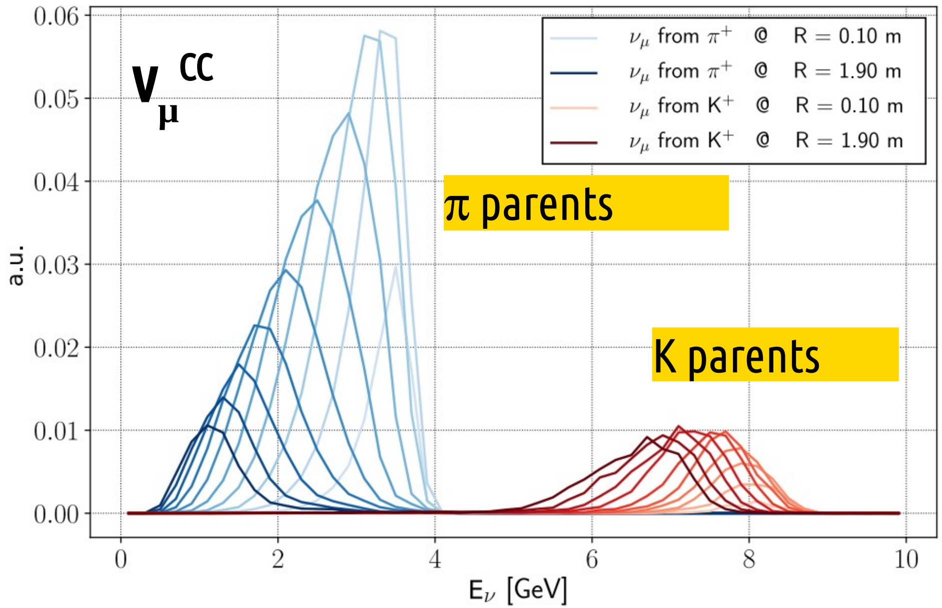
The protoDUNE(s) could be such a detector (an evident asset for a possible siting at CERN)

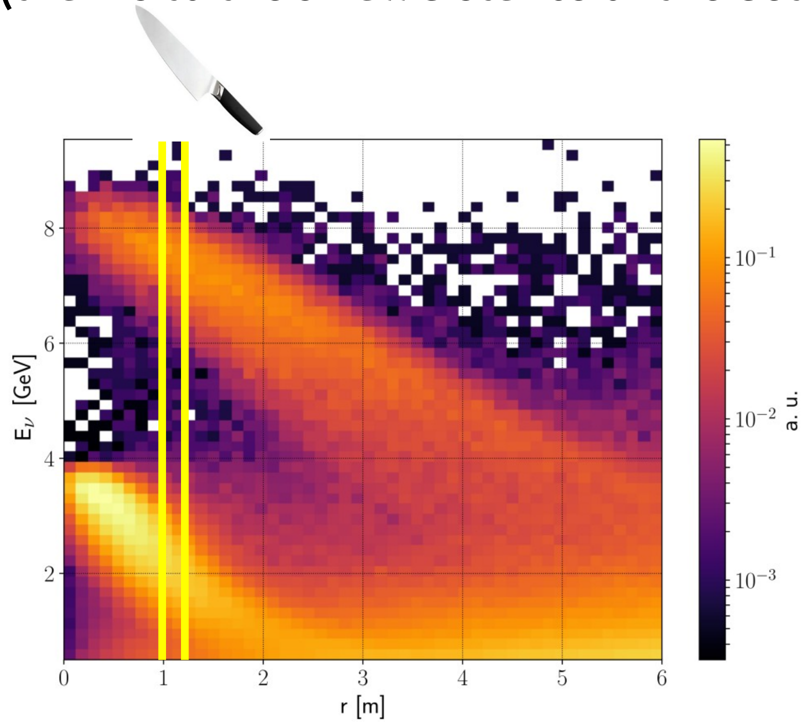




ν_μ fluxes decomposition: NBOA (~PRISM)

"Narrow-band off-axis technique" (NBOA): bins in the **radial distance from the center of the beam** → **single-out well separated neutrino energy spectra** → strong prior for **energy unfolding**, independent from the reconstruction of interaction products in the neutrino detector. "Easy" rec. variable. A kind of "off-axis" but without having to move the detector (thanks to the small distance of the detector) !





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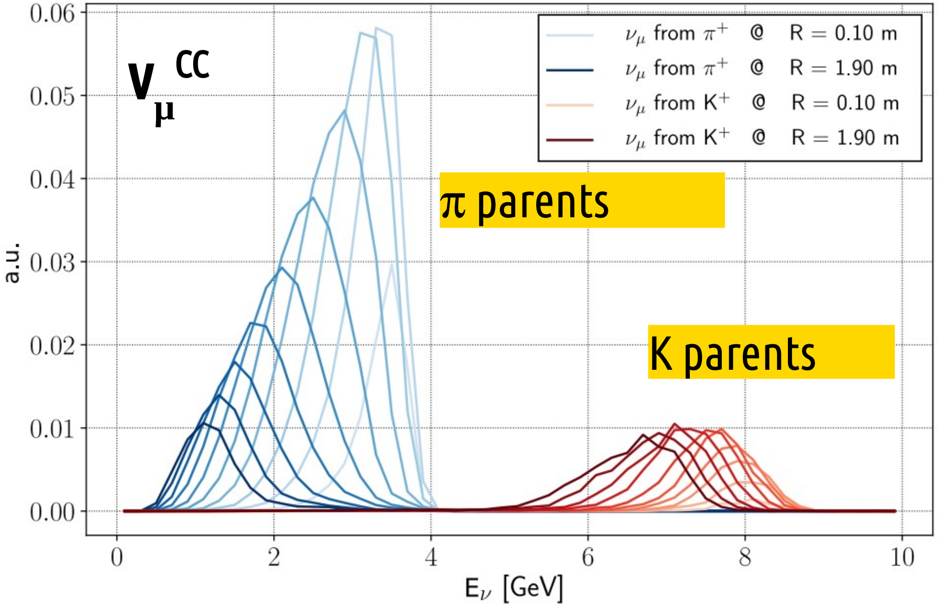
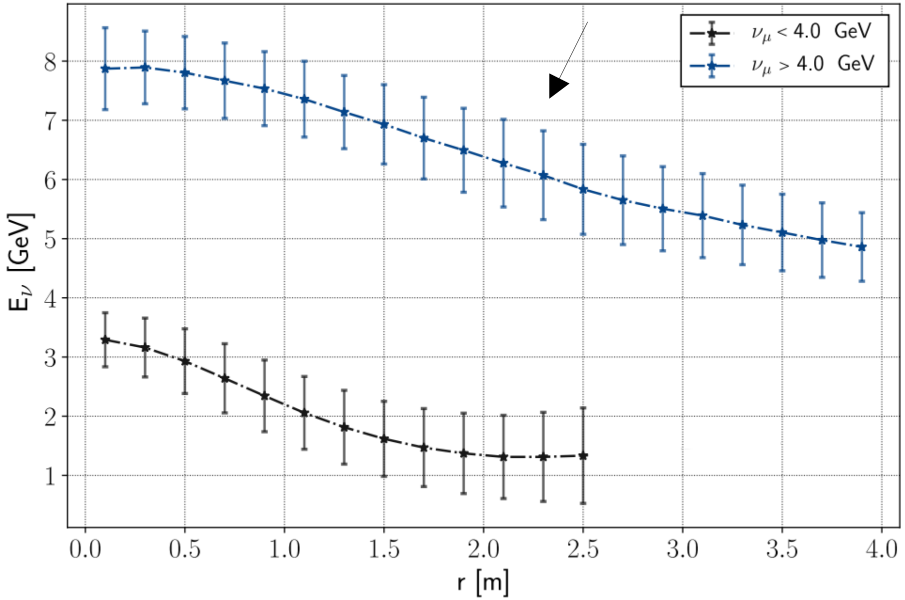


Error bands visualize the rms of the energy distributions

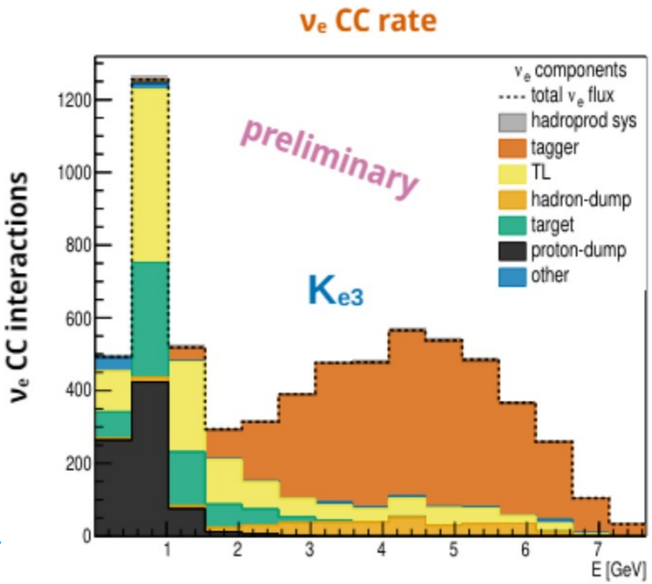


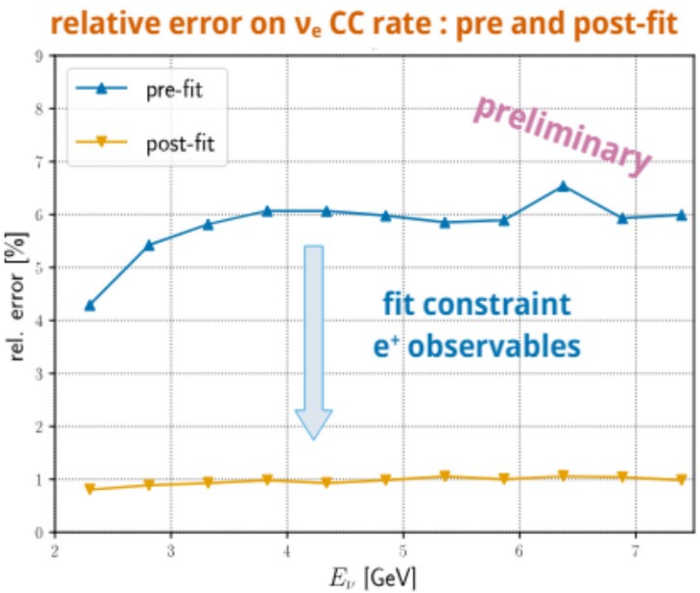
Precision on the neutrino flux

- considered the dominant sys. (hadroproduction) extracted from hadroproduction experiments at the SPS (NA56/SPY), which gives a 6% uncertainty on flux
- added as an additional prior the rate, position and energy distributions of positrons from K decay reconstructed in the tagger

Flux uncertainty for ν_μ and ν_e drops from 6% to 1% using positrons only. Further improvements expected by adding the reco. muons

F. Bramati poster at Neutrino2024

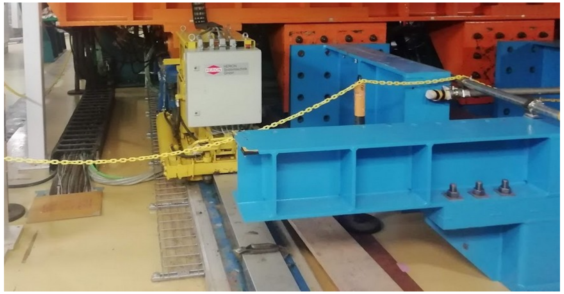




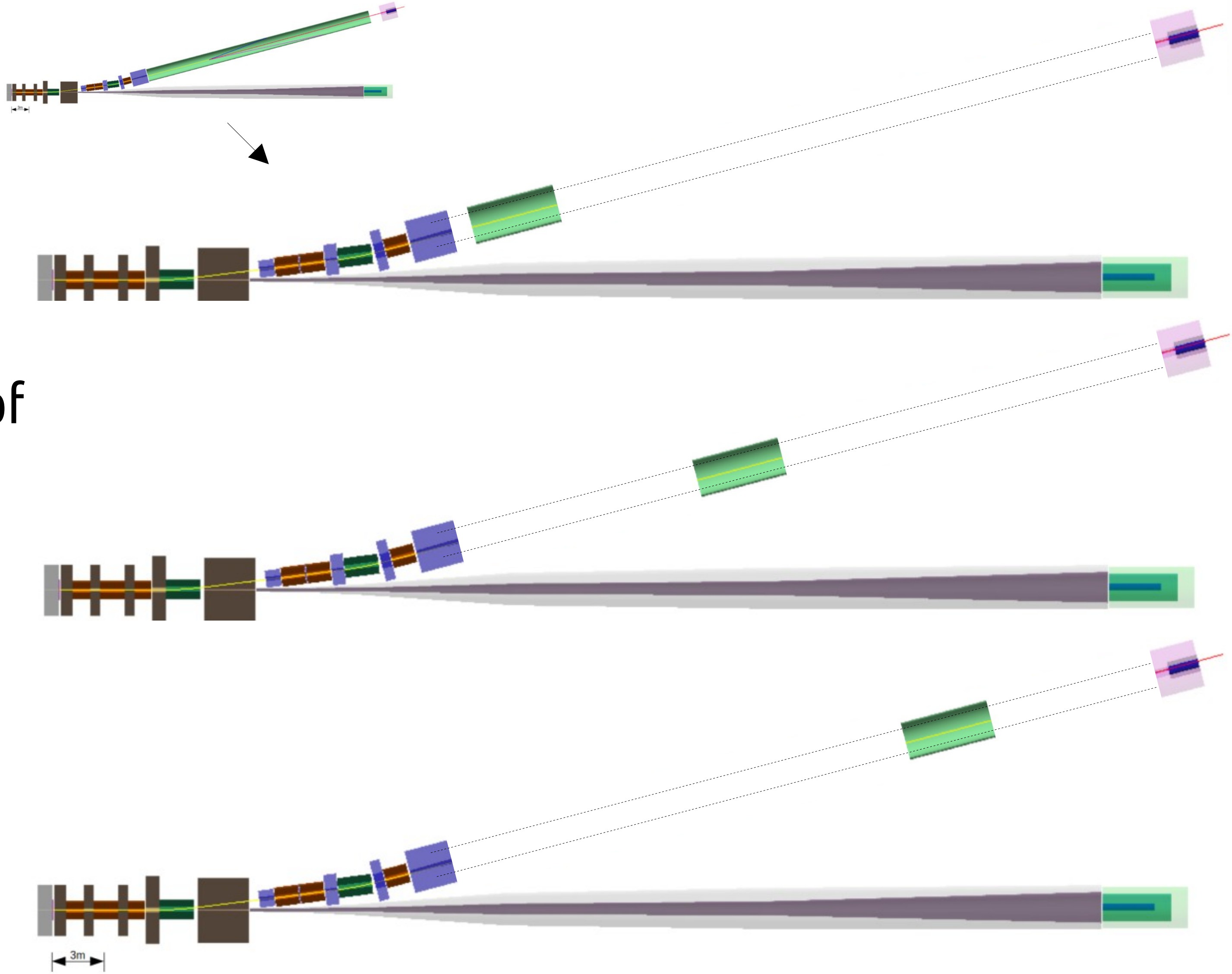
In progress: add detector effects, magnet currents, beam component, material budget uncertainty, and exploit the additional constraints from reconstructed muons (paper in preparation)

An option?

Study the systematics introduced but a partial "instantaneous" coverage of the full decay region



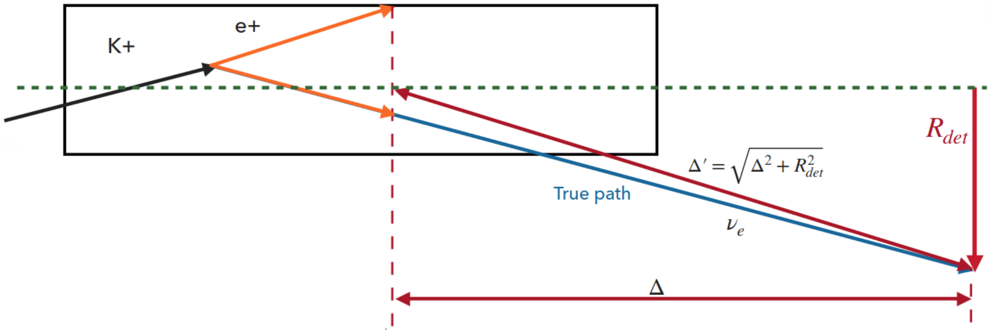
UA1/NOMAD/T2K magnet rail system



- NP06/ENUBET: a monitored beam at 400 GeV (meas. decay products)
  - Beamline design and performance
  - Lepton event-by-event reconstruction
  - Achievable ν^{CC} event spectra/rates and systematics reduction
  - **Time tagging scenarios**

t-tagging for interacting ν

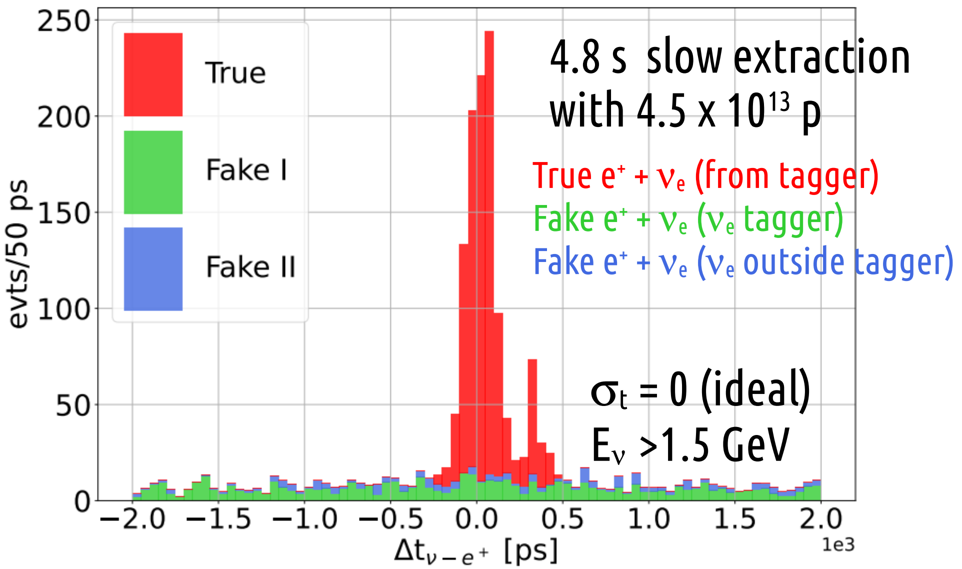
EPJ-C 83, 964, (2023)



The goal of ENUBET (monitored beam): get a sample of associated leptons to constrain the flux. To do this an event-by-event information is needed. Timing has to be "just" good enough to limit the pileup (not too aggressive).

$\Delta t = t(\nu_e) - [t(e^+) + \Delta'/c]$

→ Time correlation btw K_{e3} e^+ and ν_e candidates with the full simulation (reconstruction, backgrounds) →



Difference in path between the e^+ and ν_e (decay vertex position is unconstrained → we assume e^+ and ν_e to be collinear) → **"irreducible" time spread**: **$\sigma_{\Delta t}$ = 74 ps(*)**

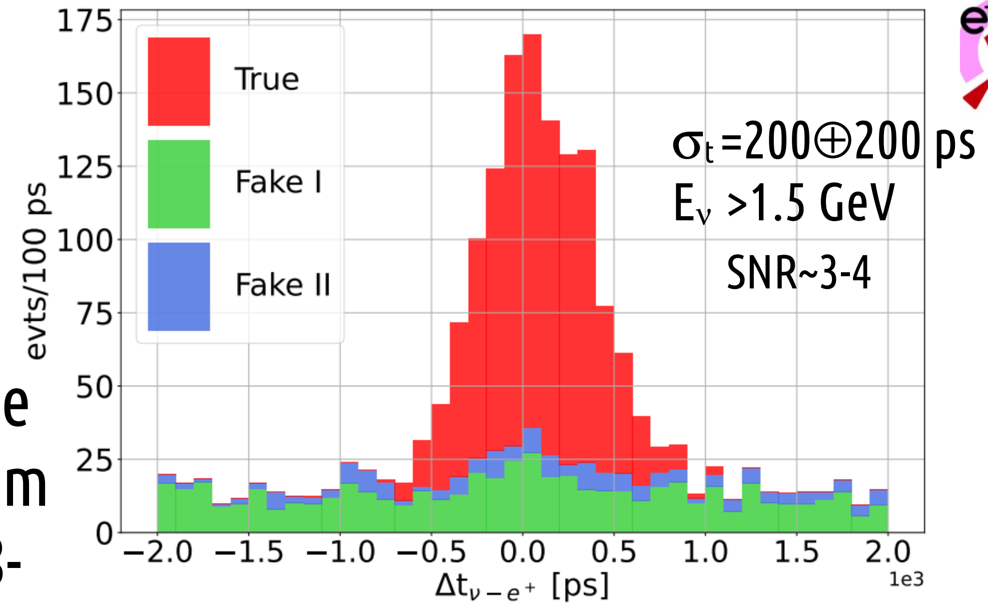
(*) already corrected for the position of the neutrino vertex
(**) could improve decreasing the tagger radius

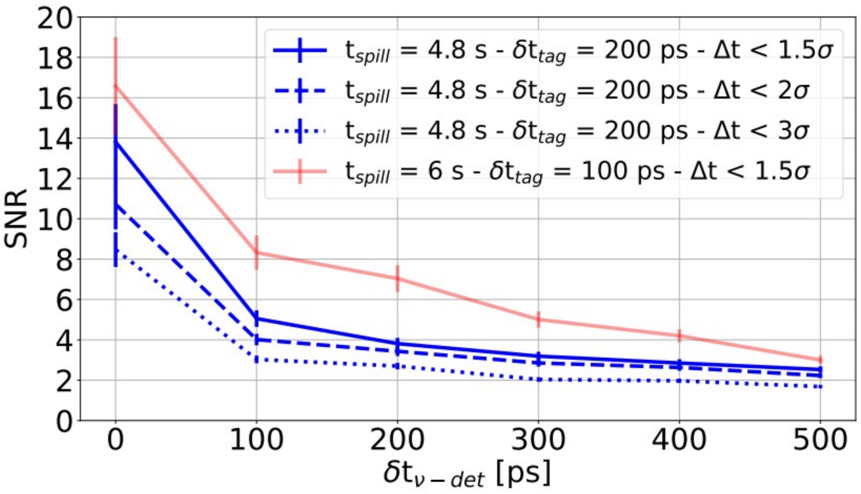
ENUBET & time-tagging

EPJ-C 83, 964, (2023)

By applying a cut on the Δt bewteen the ν_e and e^+ candidates the SNR passes from ~2 (for the inclusive e^+ sample) up to ~8-10 for neutrino-associated e^+

Precise value depends on σ_t of tagger and neutrino detector and the slow extraction spill duration





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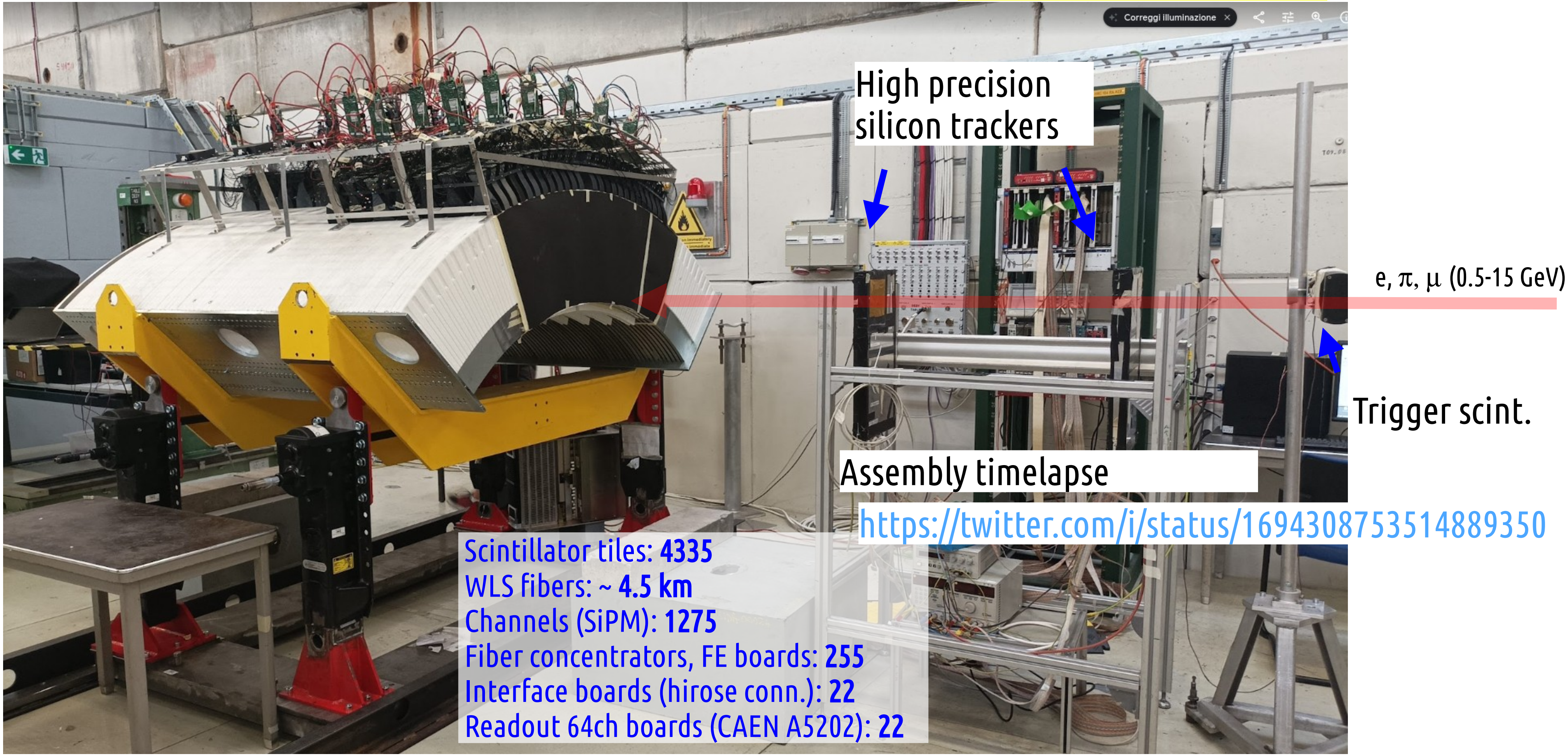
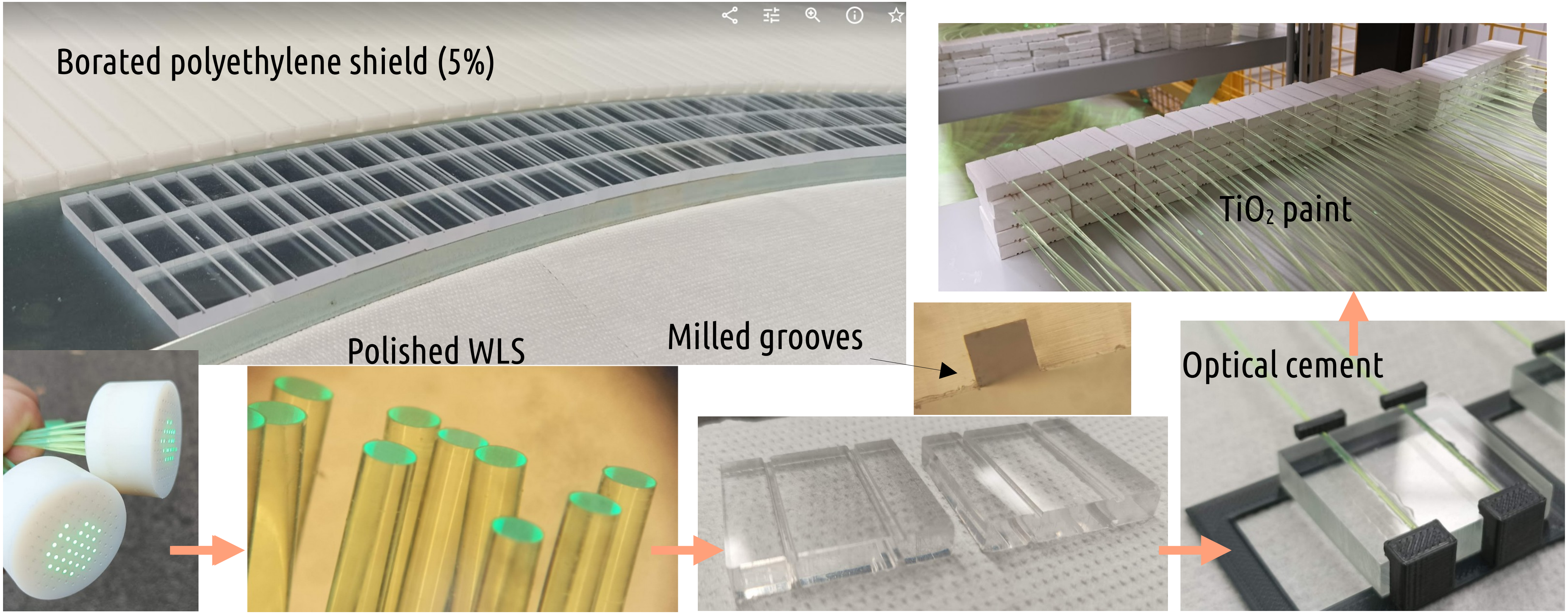
  - Time tagging scenarios
  - **The prototype - demonstrator**

The ENUBET tagger demonstrator

10/22 + 08/23 + 08/24 @ CERN-PS-T9

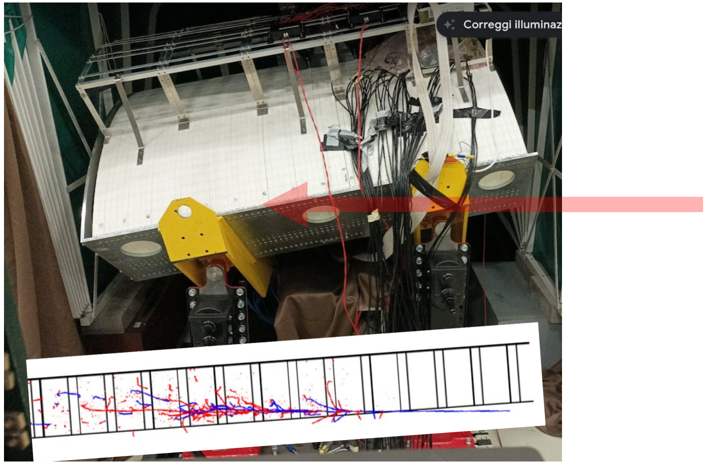


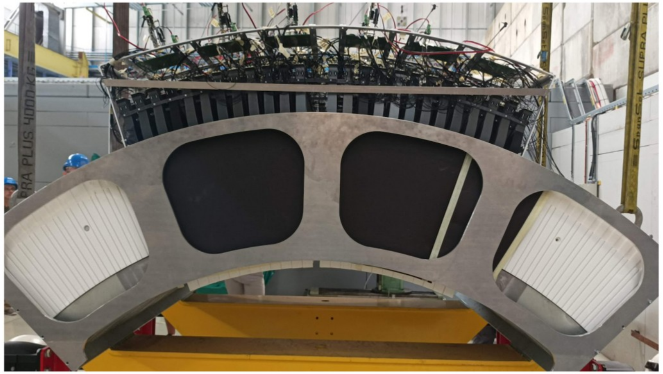
The demonstrator detector technology



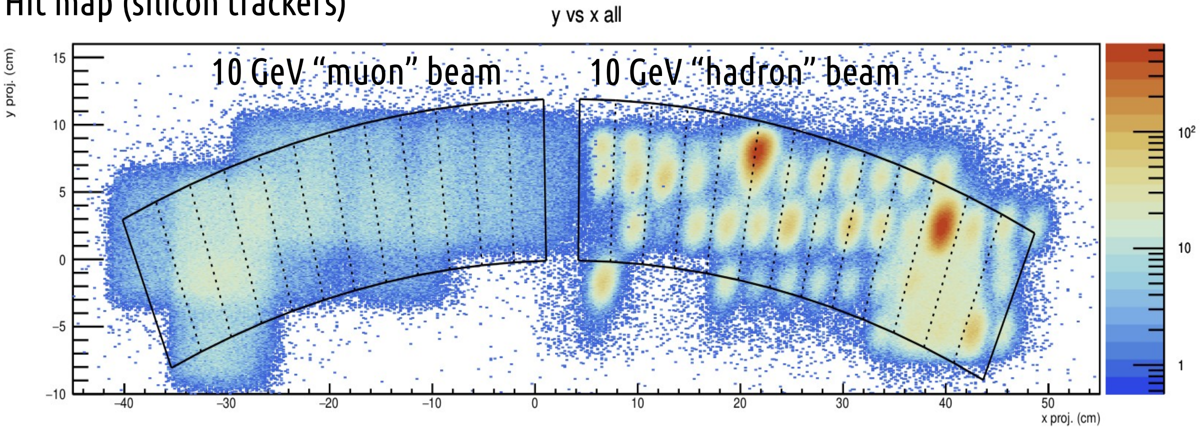
Examples: inclined and calibration runs

200 mrad tilt run

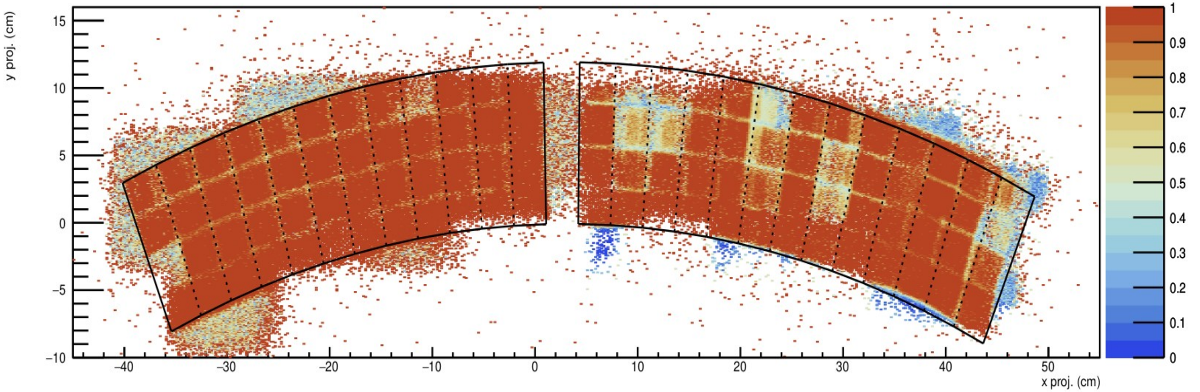




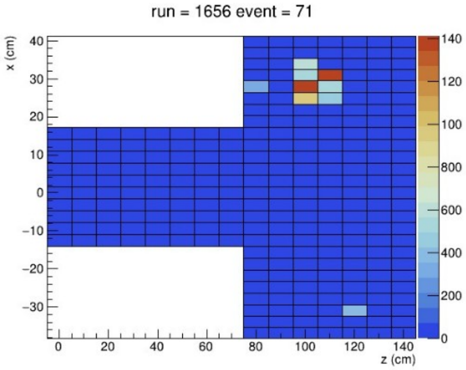
Hit map (silicon trackers)

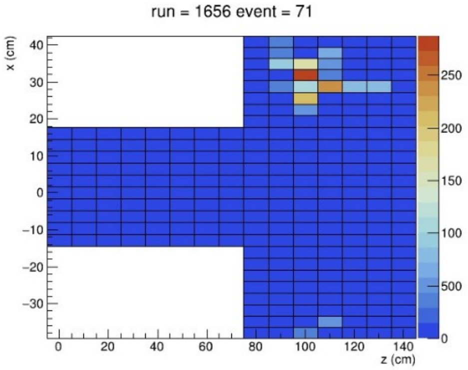


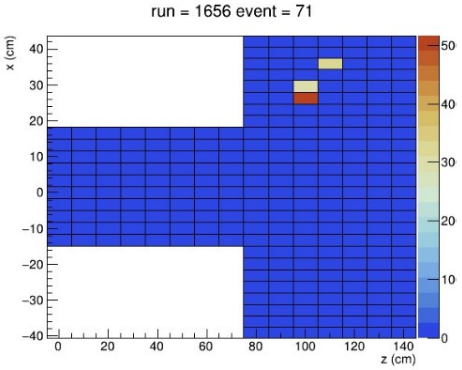
Efficiency map

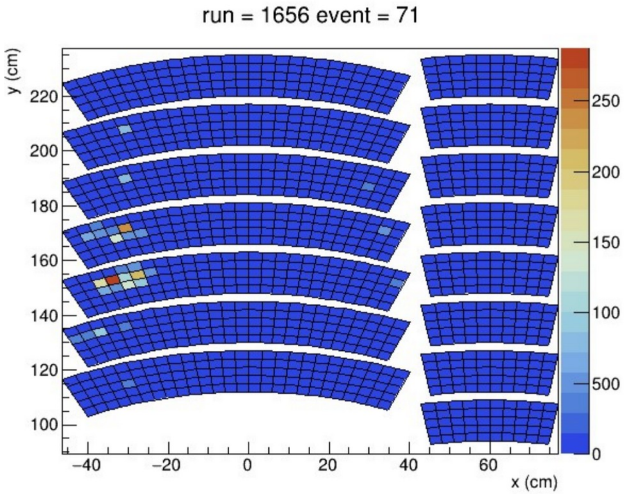


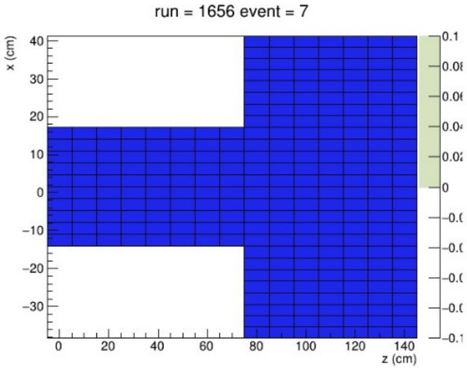
Event display (10 GeV hadrons and muons)

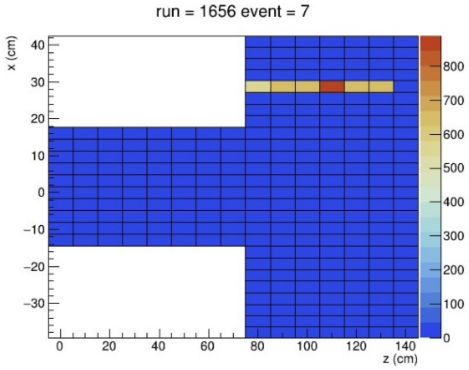


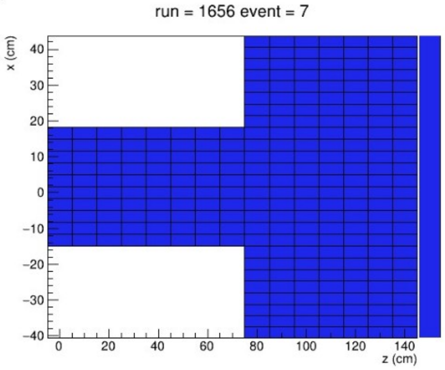


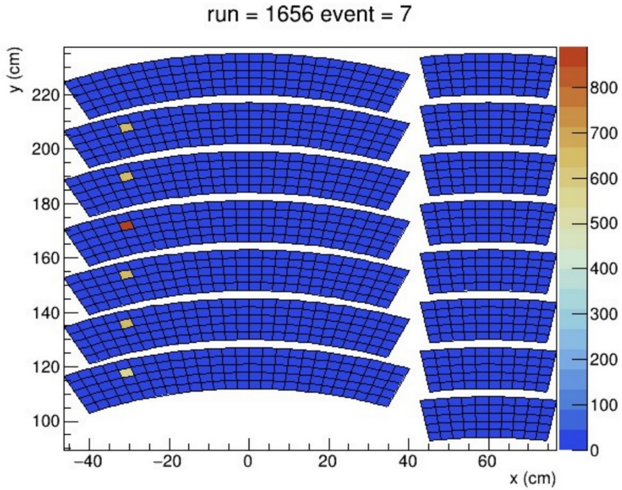




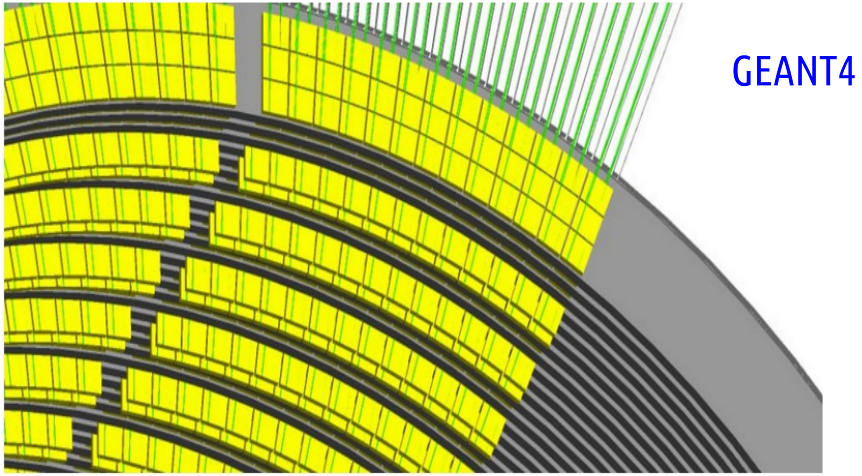


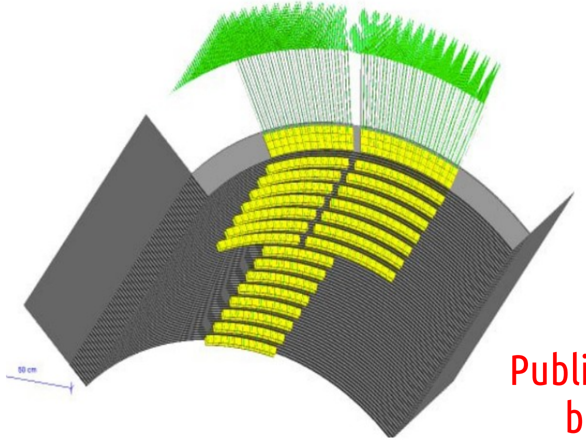


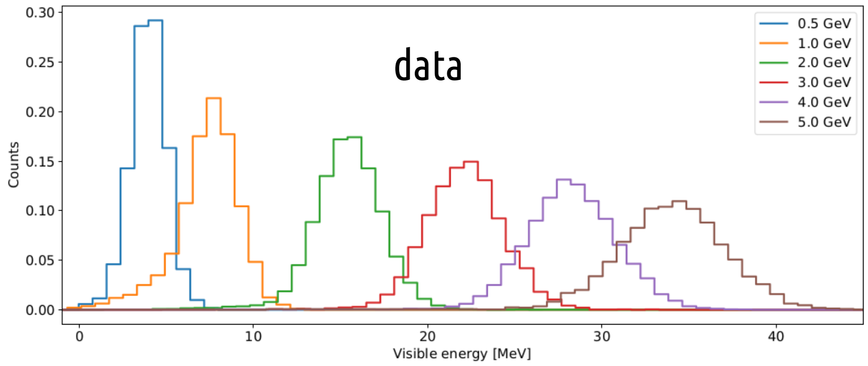


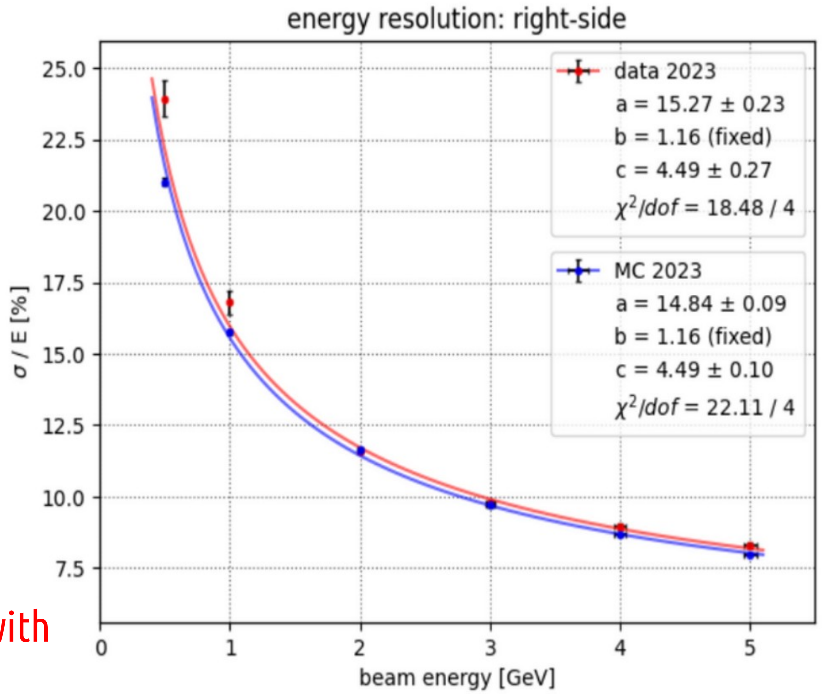


Electron energy resolution





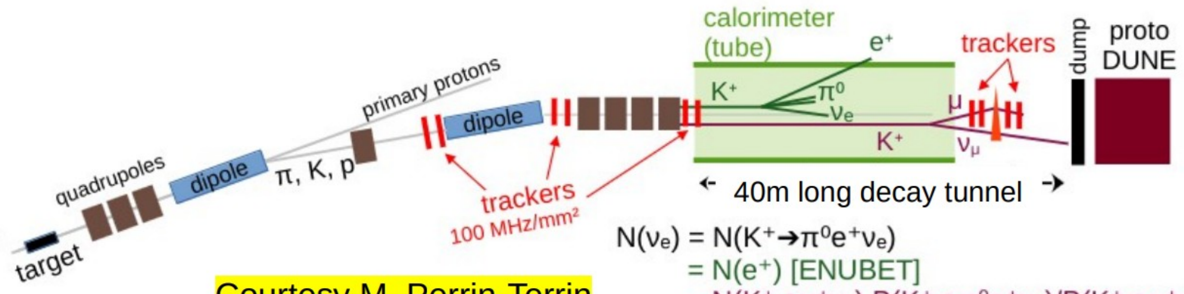




Publication in the pipeline with both 2022 and 2023 data

- NP06/ENUBET: a monitored beam at 400 GeV (meas. decay products)
  - Beamline design and performance
  - Lepton event-by-event reconstruction
  - Achievable ν^{CC} event spectra/rates and systematics reduction
  - Time tagging scenarios
  - The prototype - demonstrator
- **Going even beyond: NuTAG (tracking of neutrino parents)**

NuTAG: pushing on σ_t(tagger) and $\sigma(E_\nu)$



Courtesy M. Perrin-Terrin

$N(\nu_e) = N(K^+ \rightarrow \pi^0 e^+ \nu_e)$
$= N(e^+)$ [ENUBET]
$= N(K^+ \rightarrow \mu^+ \nu_\mu)\, B(K^+ \rightarrow \pi^0 e^+ \nu_e)/B(K^+ \rightarrow \mu^+ \nu_\mu)$ [NuTAG]

NuTAG: state-of-the-art silicon trackers with excellent timing ("4D")
→ tag the parent of the decay

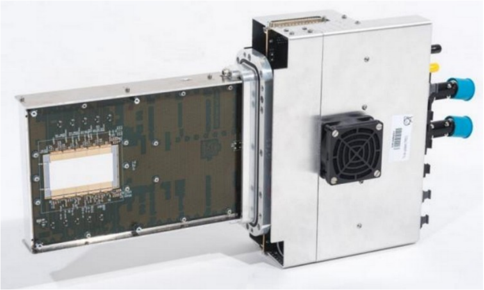
	Available	Max. Radiation	Max. Flux
NA62-GTK	since 2015	10^{14} n_{eq}/cm²	2 MHz/mm²
HL-LHC	before 2028	10^{16-17} n_{eq}/cm²	10-100 MHz/mm²

Ideal for 2-body decays ($\pi_{\mu 2}$, $K_{\mu 2}$) to reconstruct E_ν

- $p_{\pi/K}$ (parent momentum): tracking before and after a dipole
- θ_ν (with the interaction vertex in the detector)

$$E_\nu = \frac{\left(1 - m_\mu^2 / m_\pi^2\right) p_\pi}{1 + \gamma^2 \theta_\nu^2}$$

Large BR statistics: low-intensity runs.
Flux of ν_e: inferred from knowledge of B.R.($K_{\mu 2}$)/B.R.(K_{e3})
If μ can also be tracked: predict the ν position -> Relax time matching



Could provide E_ν resolutions at the % level. Studies progressing.
Challenges: upgrade of NA62 GigaTracker, reconstruction.

A. Baratto-Roldan et al. arXiv: 2401.17068

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- **Physics Beyond Colliders study**

PBC-SBN

CERN Physics Beyond Colliders
short baseline neutrino (PBC-SBN)

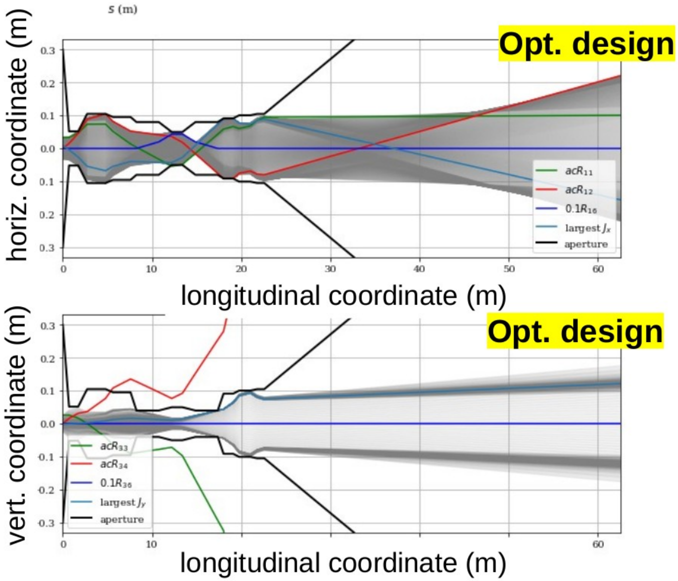
M. Jebramcik
link to talk @ PBC annual meeting
link to Neutrino2024 poster

4 directions:

- Improved design. Compatible with **ENUBET & NuTAG** — worked out
- **Compatible with the CERN fixed target programme** (more ν with less p) — worked out
- with fluxes down to **O(1) GeV → Hyper-Kamiokande** — being studied
- **Conceptual level feasibility study at CERN**: siting constraints, costs — being studied

The new design uses moderately "bolder" assumptions on the quads apertures (very conservative for NP06/ENUBET) → multi-objective optimization, CNGS-like target, shorter line →

1.4 × 10^{-3} K^+/pot → 3.5 × higher Large gain! → physics performences of ENUBET with this beamline is in progress (~ similar S/B).



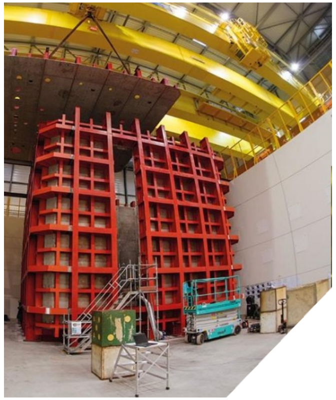
PBC-SBN perspectives

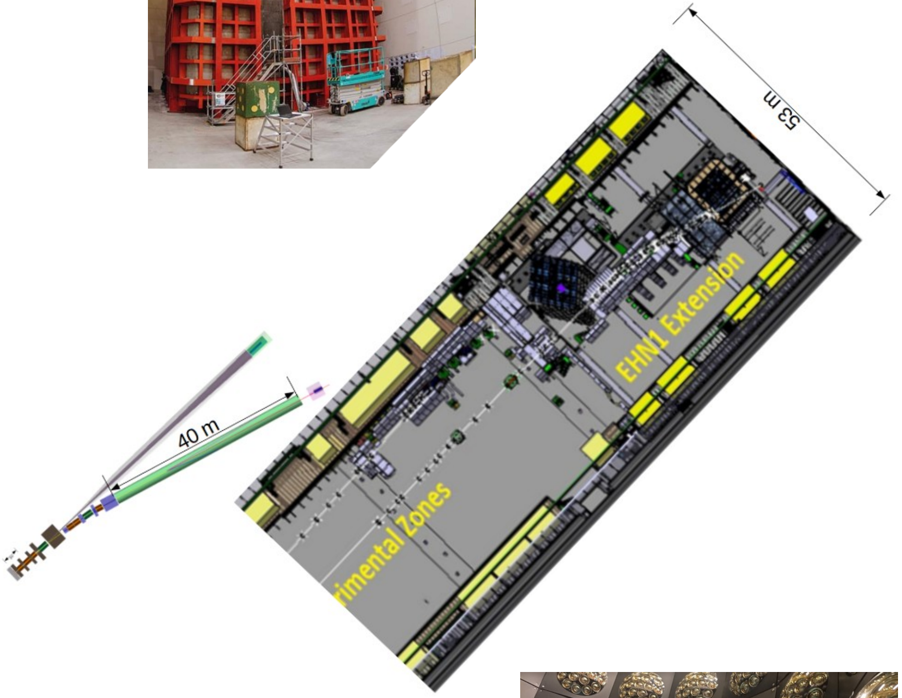
These recent studies shows that **~ 10^4 ν_e ^{CC} and 5×10^5 ν_μ ^{CC}, with a flux normalization at 1%, over ~ 5 years in a detector of similar size to the ProtoDUNEs are feasible**. Compatibly with SHiP.

Studies about possible **siting at CERN** are in progress.

Shooting on the **protoDUNEs** at the North-Area would be an ideal optimization of resources → checking feasibility/costs in practice

Other areas capable of accommodating detectors of similar size are being considered (also a WCh. detector ~ "**WCTE++**" would be extremely interesting)





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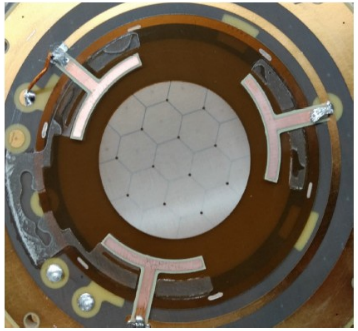
- Physics Beyond Colliders study
- **Add forward monitoring for ENUBET**

Forward monitoring with PICOSEC Micromegas

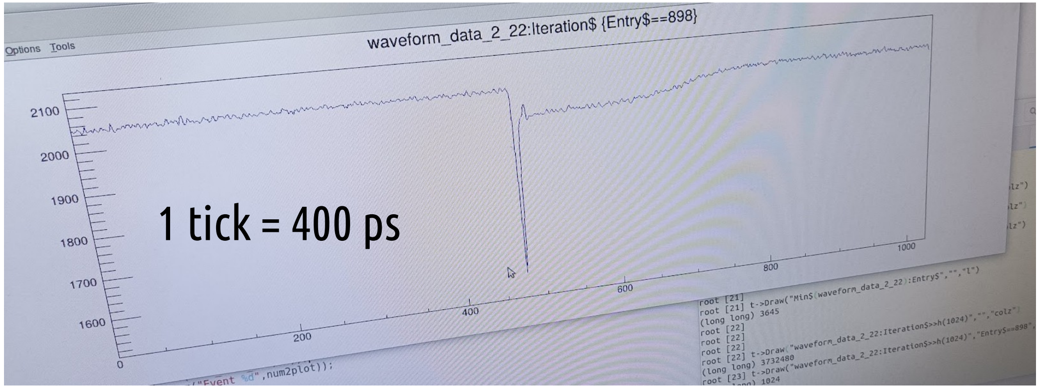
- **Instrument also the forward region**: observe μ from π decays → constrain low-E ν_μ component
- Instrumented hadron dump PIMENT (**PI**cosecond **M**icrom**E**gas for e**N**ube**T**), ANR2022-25
- Prototype tested with the ENUBET demonstrator **at T9** in Aug. 2024 → few 10s of ps resolutions achieved
- Athens, CNRS, INFN, Thessaloniki, Zagreb

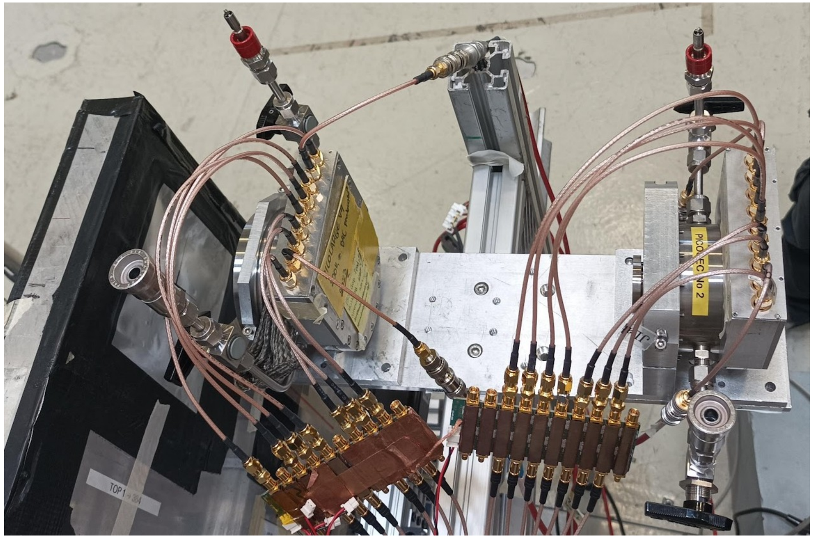


19 channel anode ⬡ 1 cm

https://doi.org/10.1016/j.nima.2018.04.033

CERN Aug. 2024





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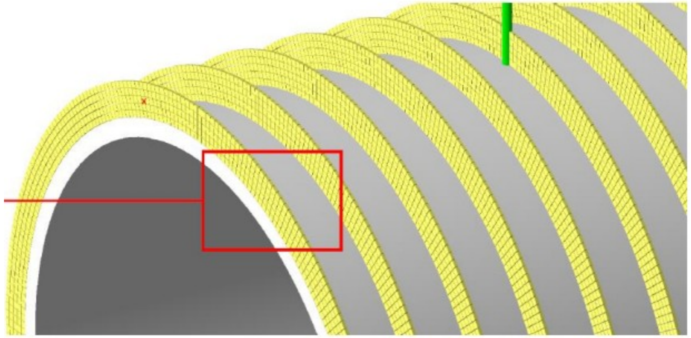
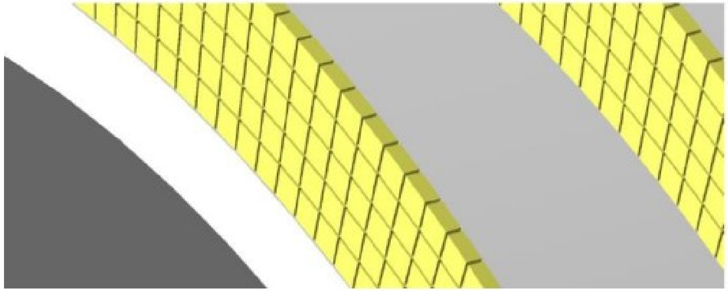
- Add forward monitoring for ENUBET
- **MNB@ESS**

A low-E_ν monitored beam at ESS ?

- MNB@ESS WP6 of the ESSnuSB
  - previous talk by Tamer Tolba
- **E_p = 2 GeV**. No K and π multiplicity very low. Mitigated by a very LARGE intensity.
- Must **monitor muons**. They are not as forward as for ENUBET due to lower boost → cyl. geom. still OK.
- Design based on (PICOSEC) MicroMegas
- The spill structure (2.86 ms) makes **pileup** more delicate than for ENUBET (→ finer granularity 1cm^2)
- Use only a **fraction of the extracted protons**
- → Constrain on the flux **seems feasible**
- with a **sufficient statistics of neutrinos**
- End-to-end studies as for ENUBET being carried on



A. Branca link



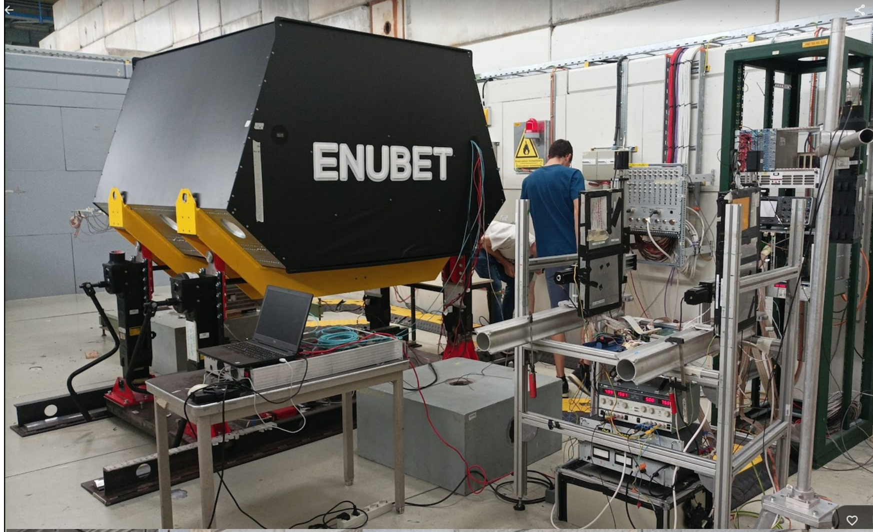
	ENUBET@CERN	MNB@ESS	Notes
Proton driver	400 GeV/c	2 GeV	At ESS we exploit pion decays and muon decays in flight [no K]
Secondaries	8.5 GeV/c	About 1-2 GeV	
Proton extraction	2 s	2.86 ms	This is a key item WP6 has assessed in 2023
Decay in flight of muons	Negligible	It is the main source of ν_e at the ESS	

7

Conclusions

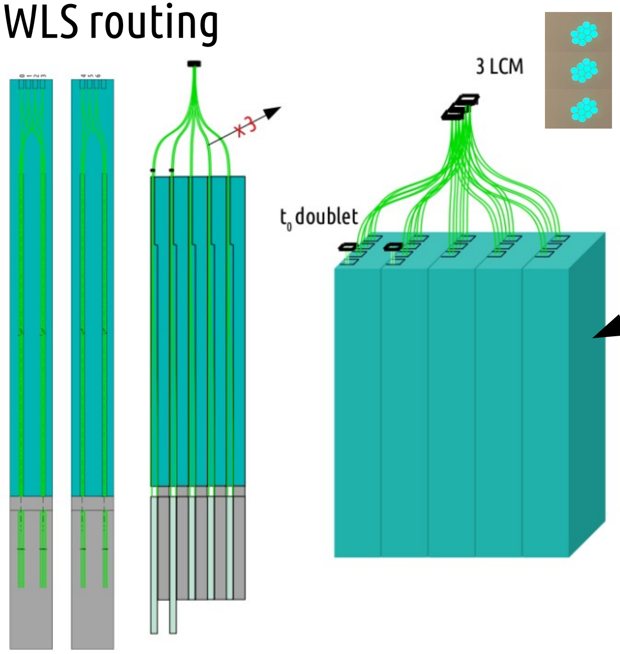
CERN Aug. 2024 →

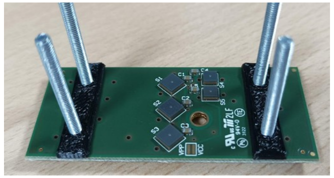
- Next two years will be crucial NP06/ENUBET
- Preparing for a dedicated **workshop Neutrinos@CERN** organized by PBC/Neutrino Platform at CERN in 23-24 January 2025
- and a **contribution to the ESPPU** process starting in spring 2025 (“European Strategy for Particle Physics Update”).
- The importance of the inclusion of an **even larger community** does not need to be emphasized!
- Thanks!



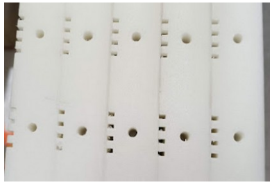
The demonstrator

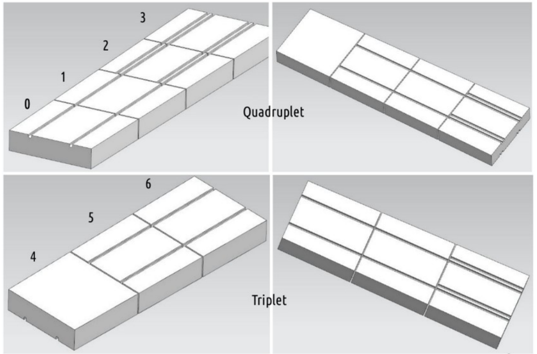
WLS routing

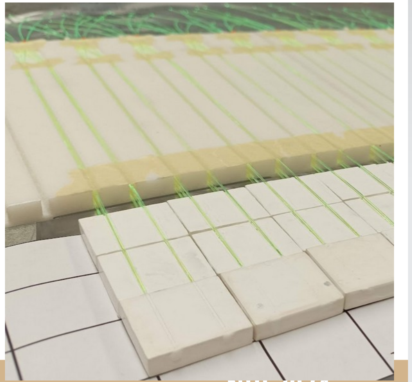




Demonstrate detector performance (PID, homogenity, eff.), scalability, cost effectivess…





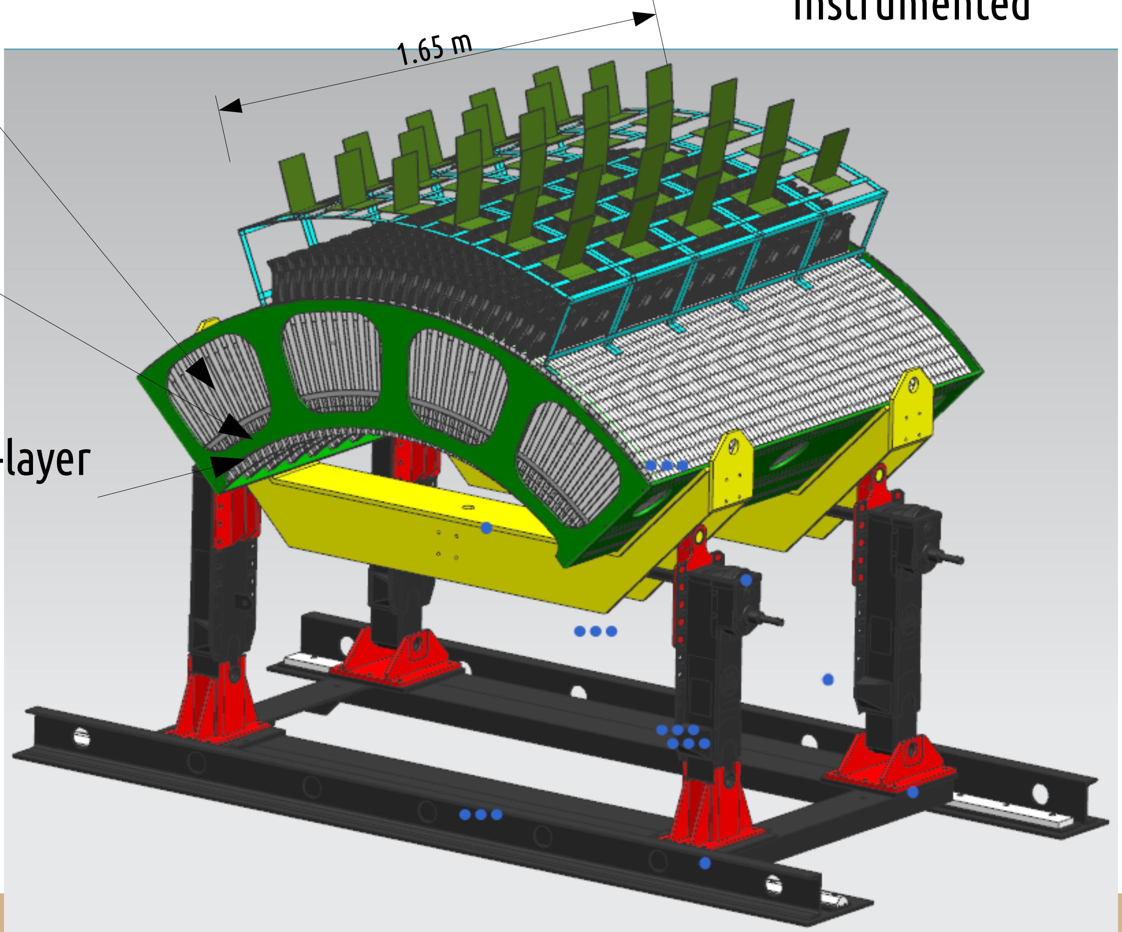


90°, partially instrumented

BPE 5%

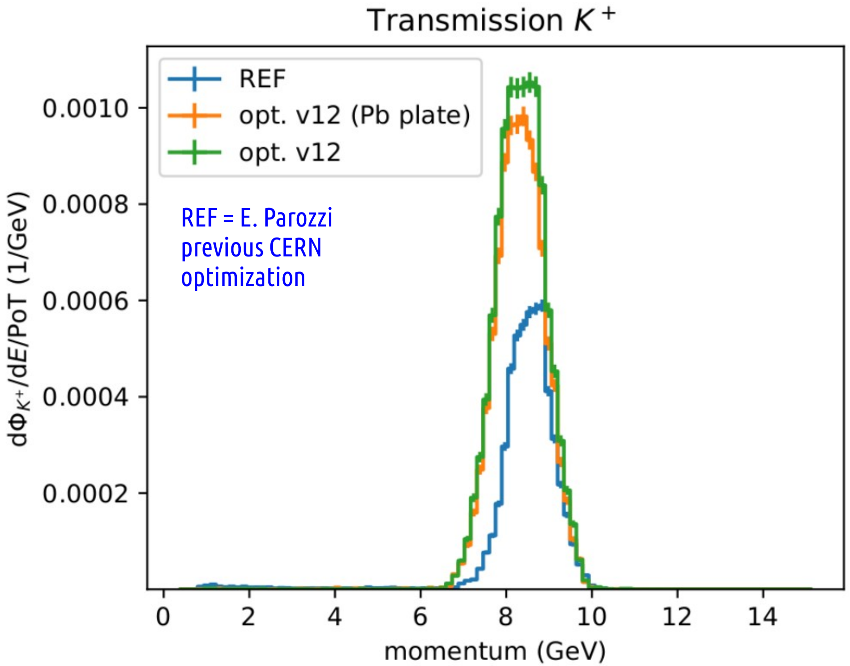
Sampling iron/scint calo

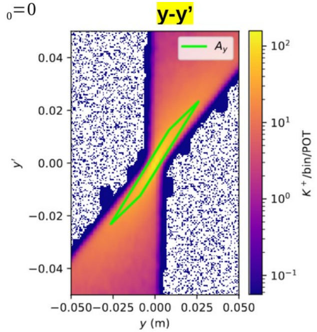
t_0-layer

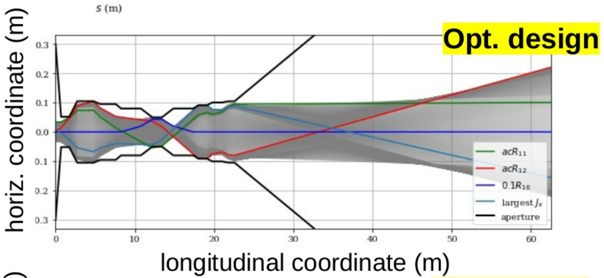


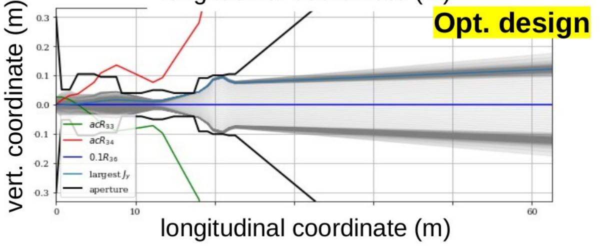
The PBC-SBN beamline optimization

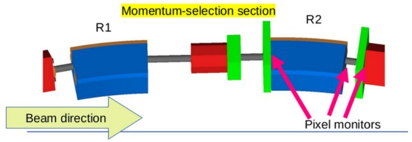
- link to the talk at the PBC annual meeting by M. Jebramcik 26/03/24
- Analyzed 16 targets, 7 drift spaces, 18 quad. parameters (6 magnets with different length, aperture, gradient) → **26 free parameters**
- **Multiple (3) objectives**: K+ & π+ transmission as possible and the beam size has to be as small as possible in the momentum selection and the decay tunnel
- 1) Linear optimization with **multi-objective genetic algorithm (MOGA)**
- 2) Verification with a start-to-end BDSIM simulation
- Optimized beamline **7 m shorter** (from 30 to 23 m). Uses a CNGS-like target
- 1.2 cm lead foil in the middle of momentum selection to suppress e^+
- **1.41×10^{-3} K^+/pot → 3.5x improvement. Huge gain! → tuning of backgrounds with the full chain is in progress (→ iteration)**

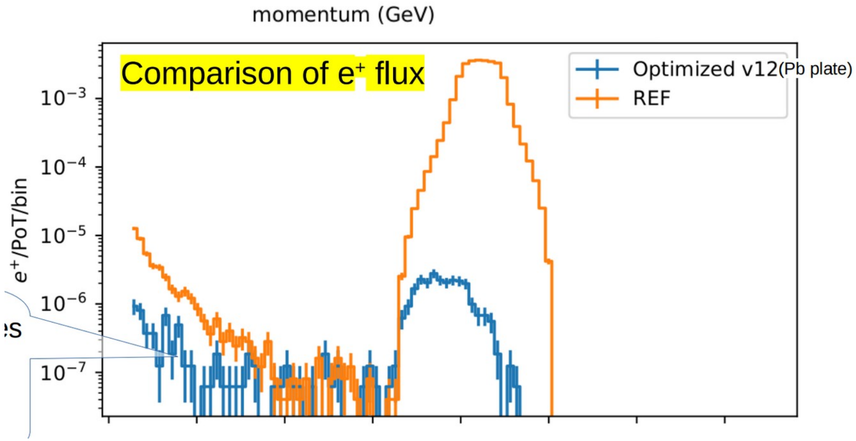








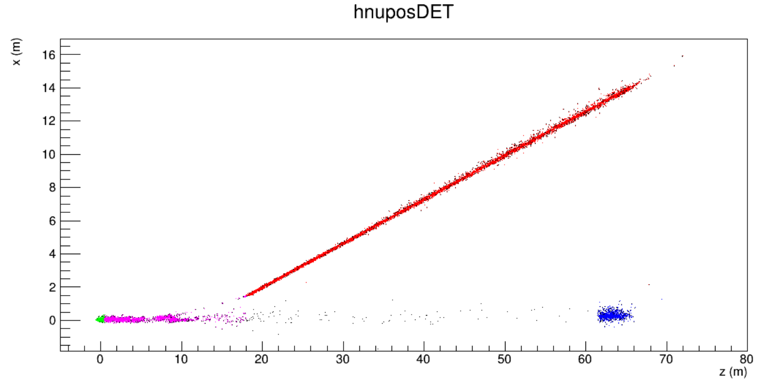


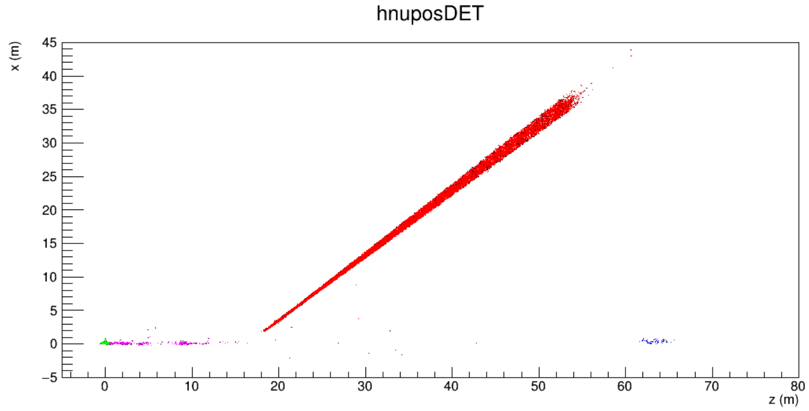


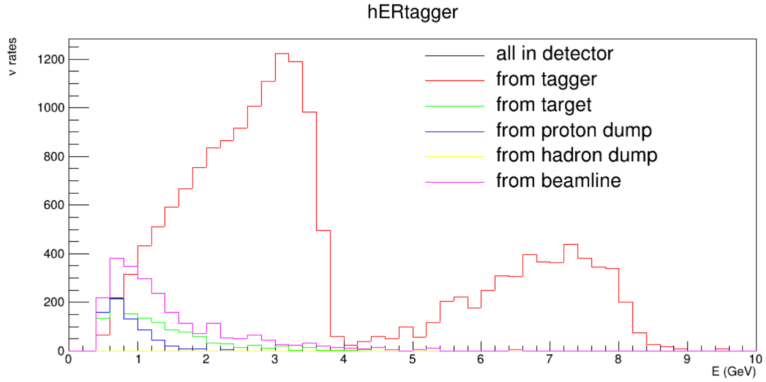
ν_μ^{CC} spectra at detector

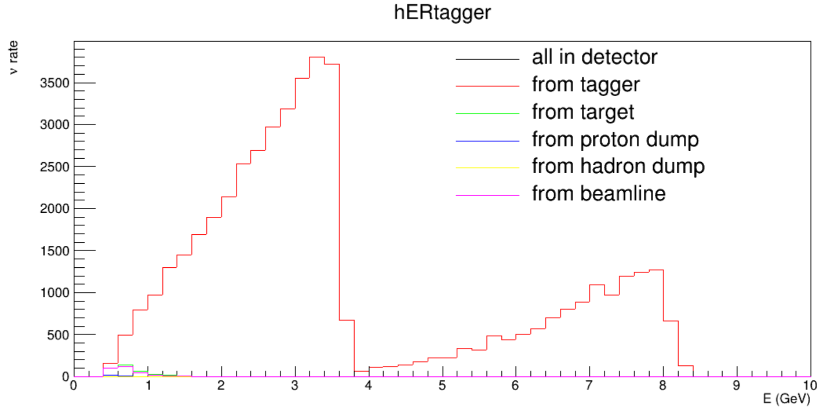
With a SC second dipole

tlr6v6





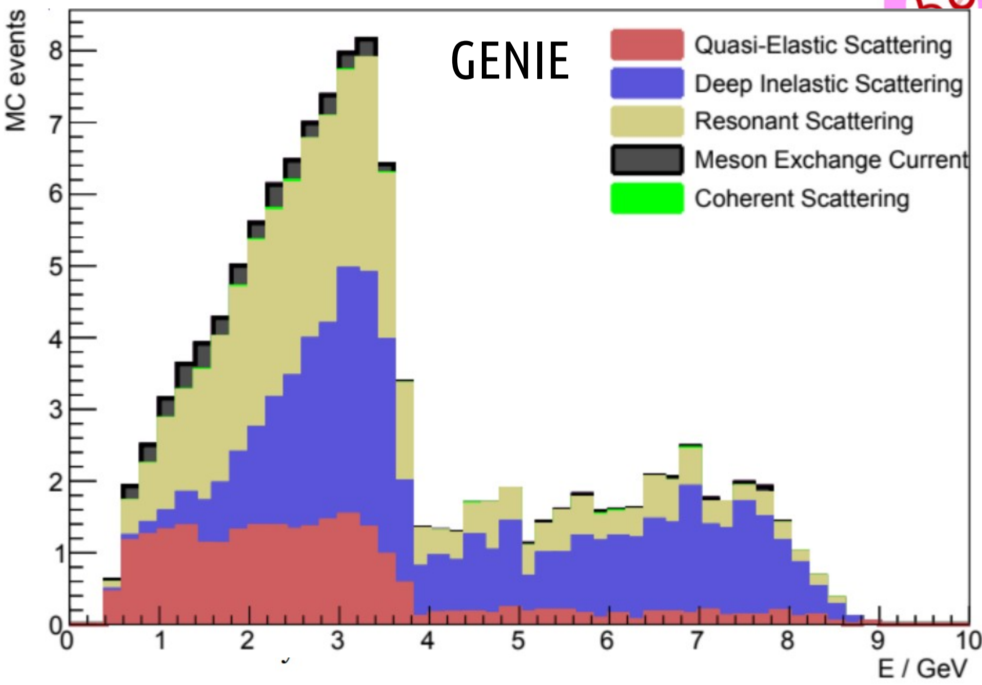


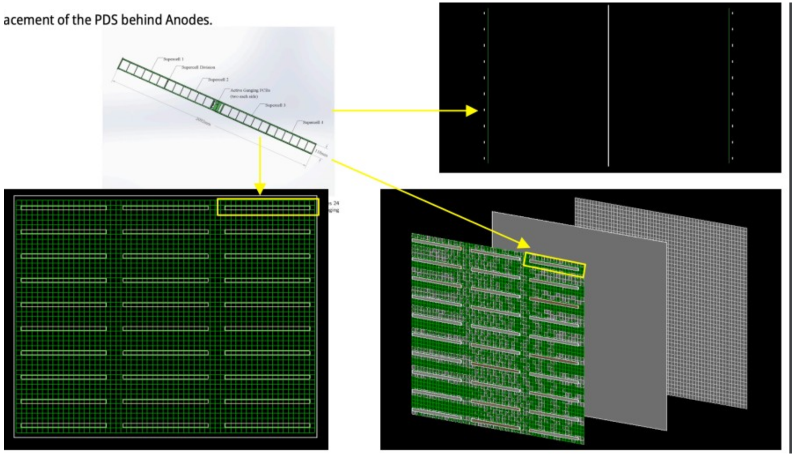


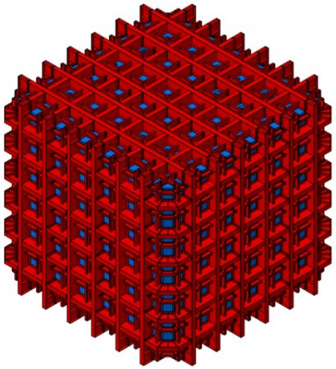
ν detector studies (ENUDET)

This R&D is being pursued by ENUBET together with the DUNE-SoLAR coll. and is instrumental in **exploiting liquid Argon in a tagged neutrino beam**. A dedicated task force is addressing:

- The **achievable σ_t of ProtoDUNE** overhauled for DUNE Phase II. It will be equipped with an **enhanced photon detection system**. The corresponding light yield will improve time resolution for GeV neutrinos below 1 ns.
- **Simulation of neutrino interactions (GENIE)** and **reconstruction effects** (i.e. role of **cosmic rays** background) to **assess the physics reach on the cross section for specific channels**

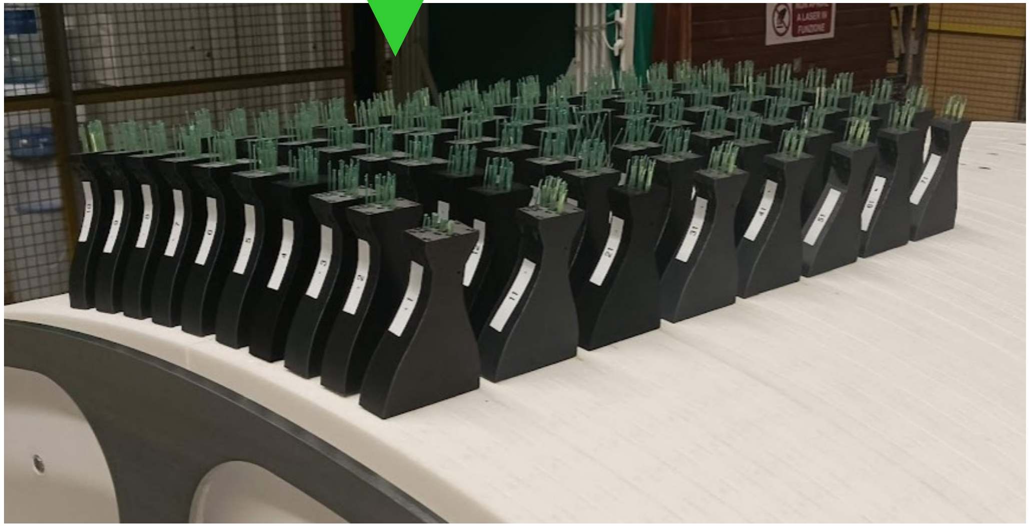


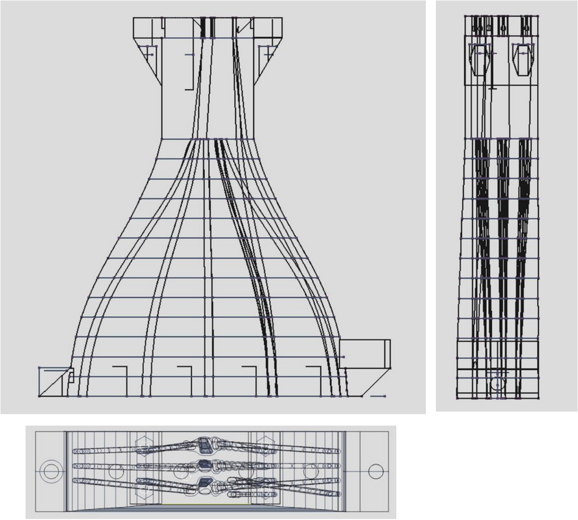




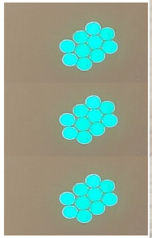
Fiber bundling with "concentrators"

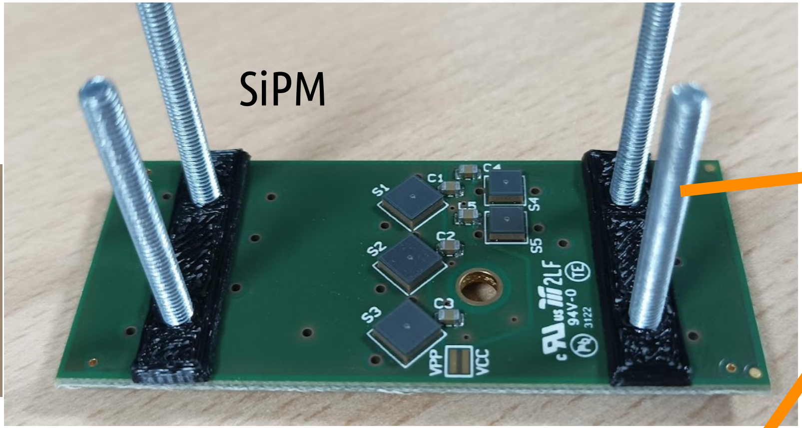
bundling of the WLS fibers with 3D printed "fiber concentrators"+ in situ polishing

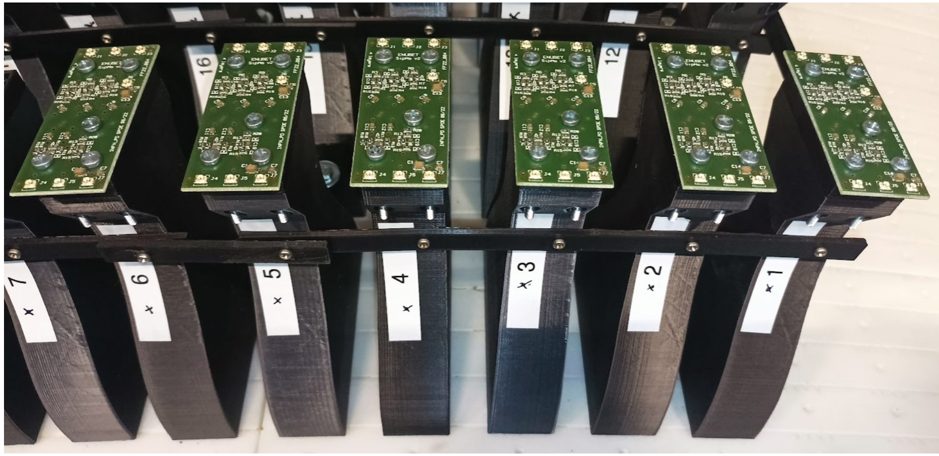


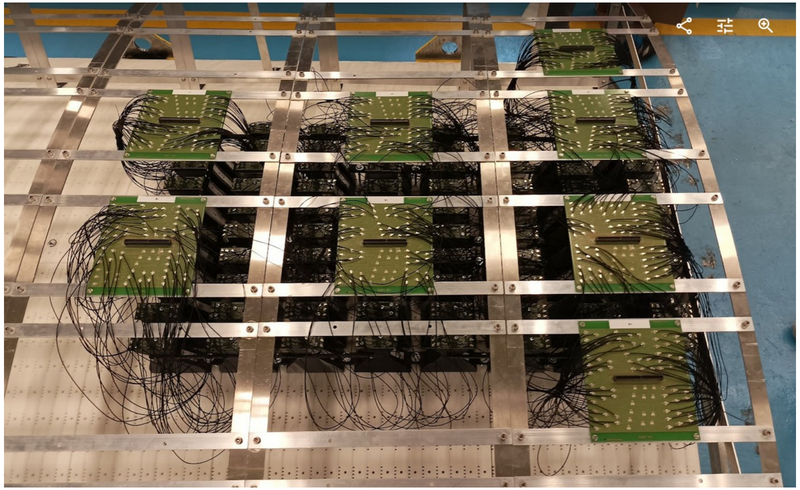


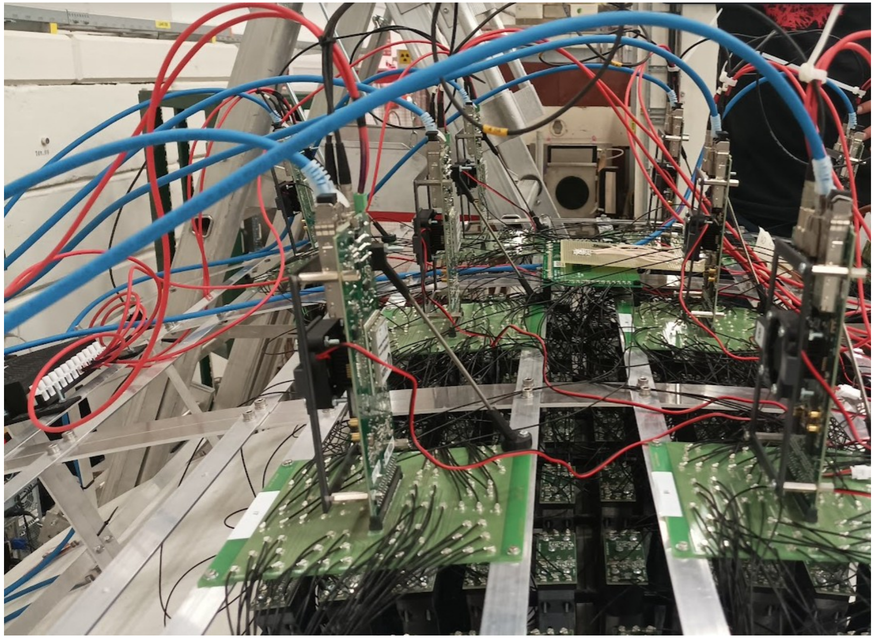
Readout scheme





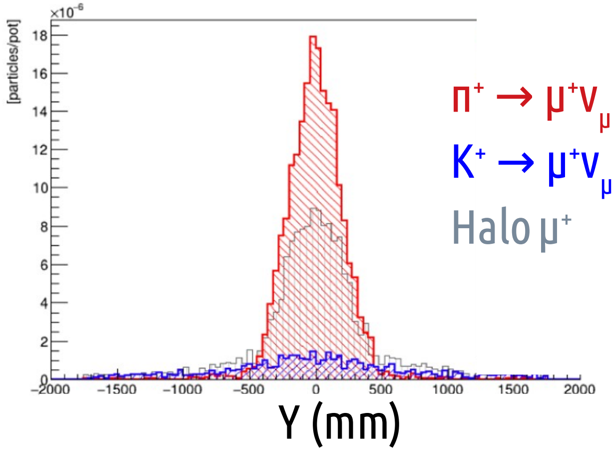


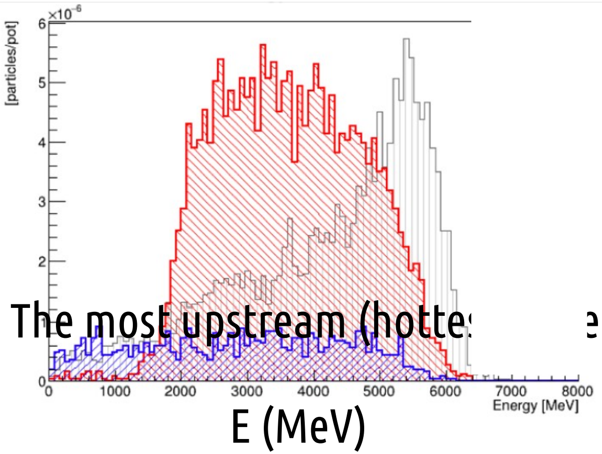


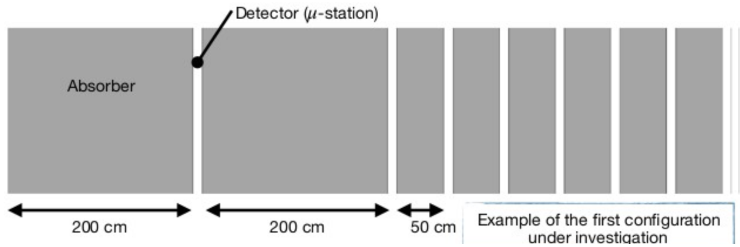


Forward region muons reconstruction

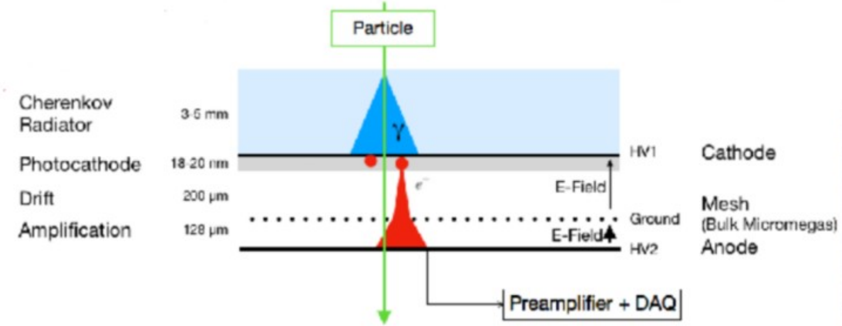
Range-meter after the hadron dump. Extends the tagger acceptance in the forward region to constrain $\pi_{\mu 2}$ decays contributing to the low-E ν_μ.

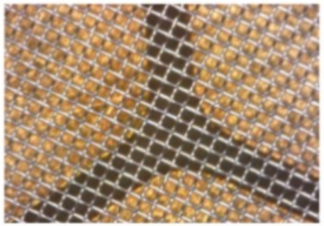






The most upstream (hottes… …ector needs to cope with a muon rate of ~ 2 MH…





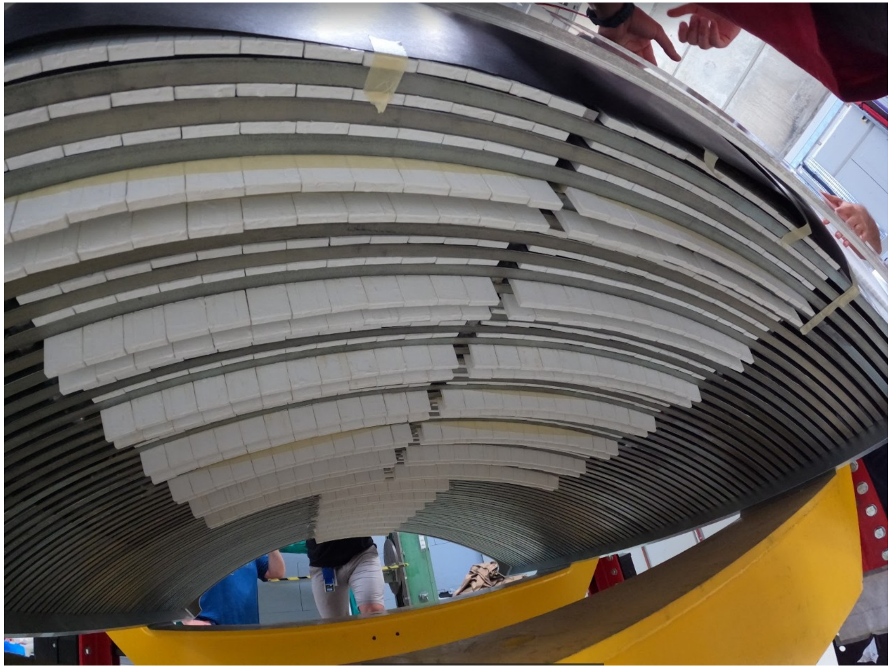
Micromegas detectors employing Cherenkov radiators + thin drift gap ?
Bonus: cutting-edge timing (O(10) ps).

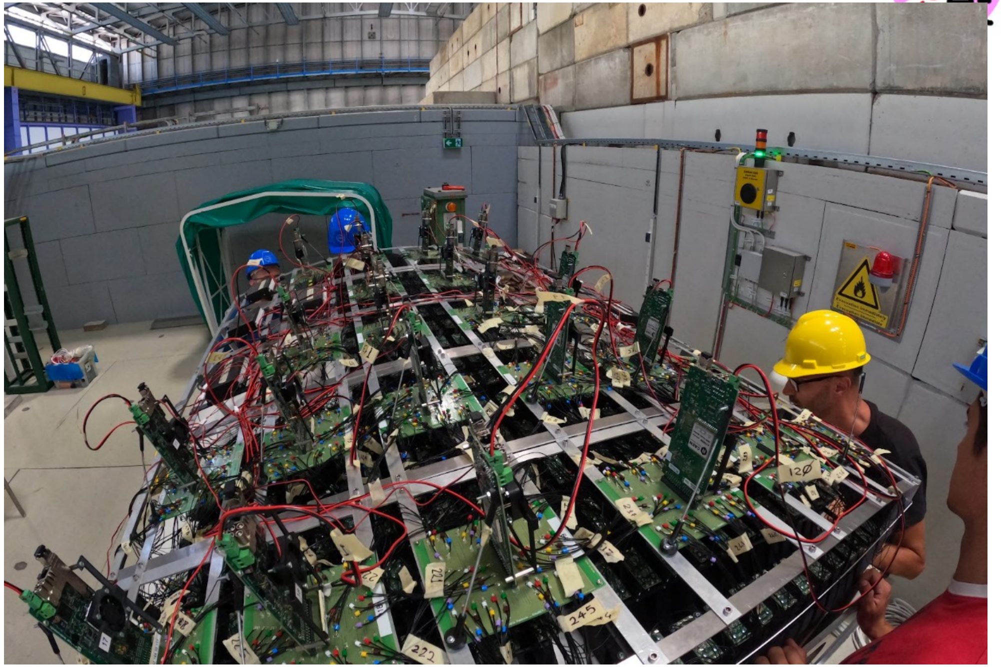
→ PIMENT project ! →

ENUBET: demonstrator

Assembly timelapse

https://twitter.com/i/status/1694308753514889350

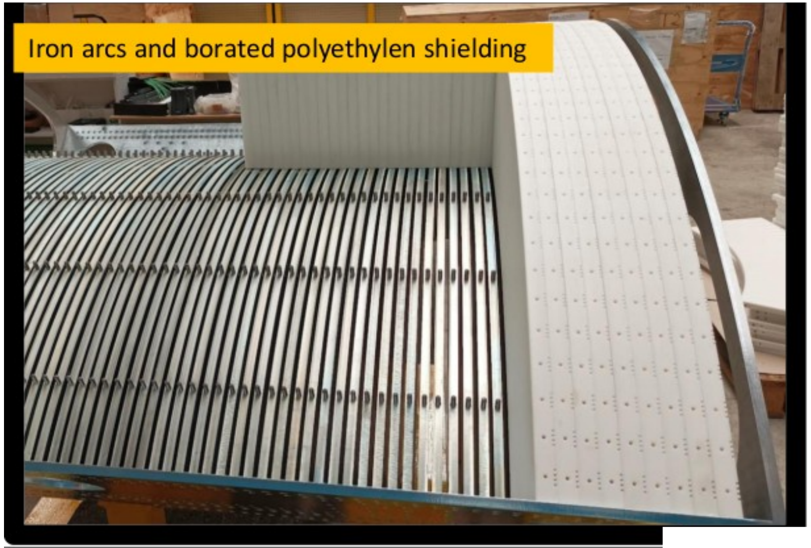


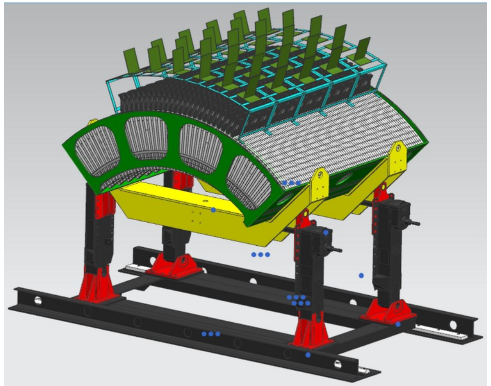


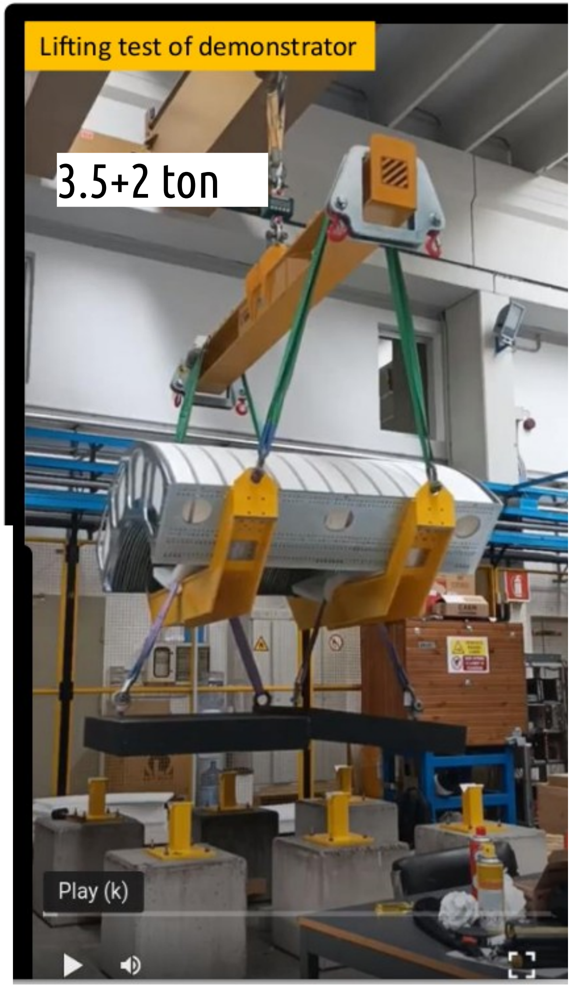
The ENUBET demonstrator in numbers

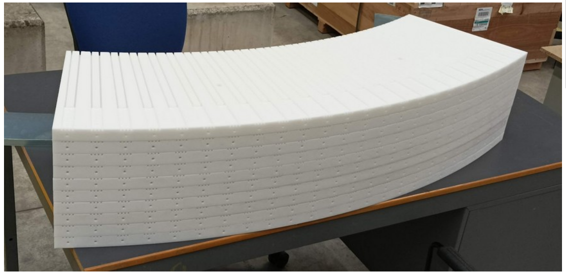
- Scintillator tiles: **1360**
- WLS: ~ **1.5 km**
- Channels (SiPM): **400**
  - Hamamatsu **50 um** cell
    - **240** SiPM **4x4** mm^2 (calo)
    - **160** SiPM **3x3** mm^2 (t_0)
- Fiber concentrators, FE boards: **80**
- Interface boards (hirose conn.): **8**
- Readout 64 ch boards (CAEN A5202): **8**
- Commercial digitizers: **45 ch**
- hor. movement ~**1m**
- tilt **>200 mrad**

Demonstrator construction at LNL-INFN labs

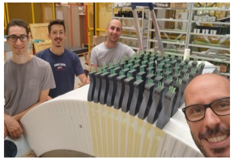




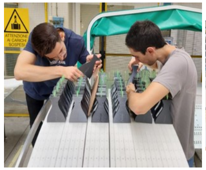


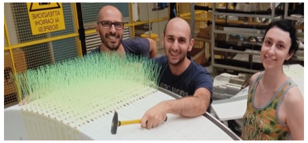


Group pictures

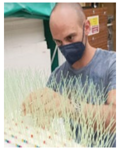


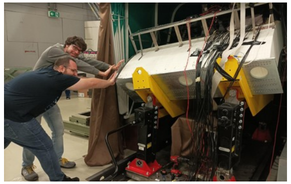








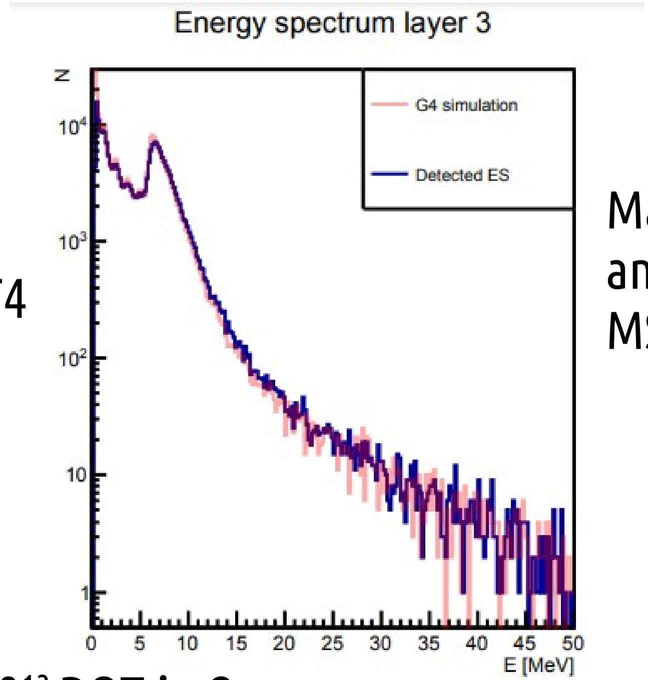




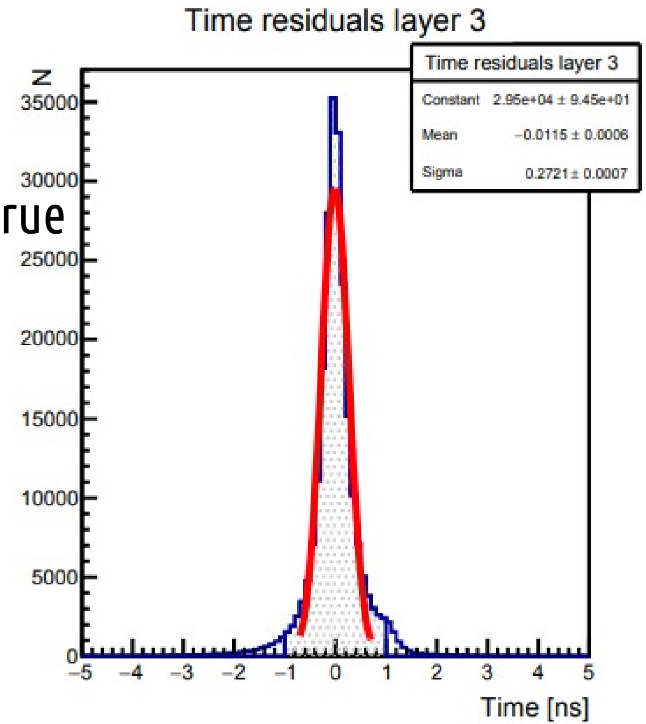
Event pile-up analysis

The energy is now reconstructed as it will happen for real data i.e. considering the **amplitudes digitally-sampled signals at 500 MS/s**. **Pile-up** effects treated rigorously by “fitting” superimposing waveforms.

Matching between true level energy deposits from GEANT4 and fully reconstructed waveforms



Matching between true and rec. time (500 MS/s). 270 ps.



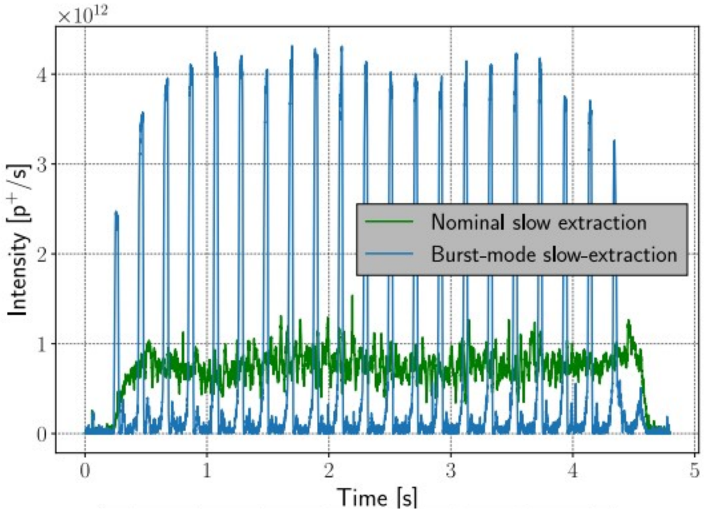
With 4.5 x 10^{13} POT in 2s

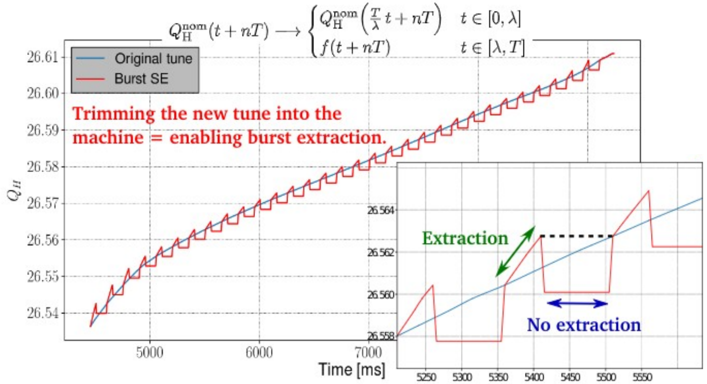
- 1.1 MHz rate in the hottest channels
- Peak finding efficiency = 97.4 %

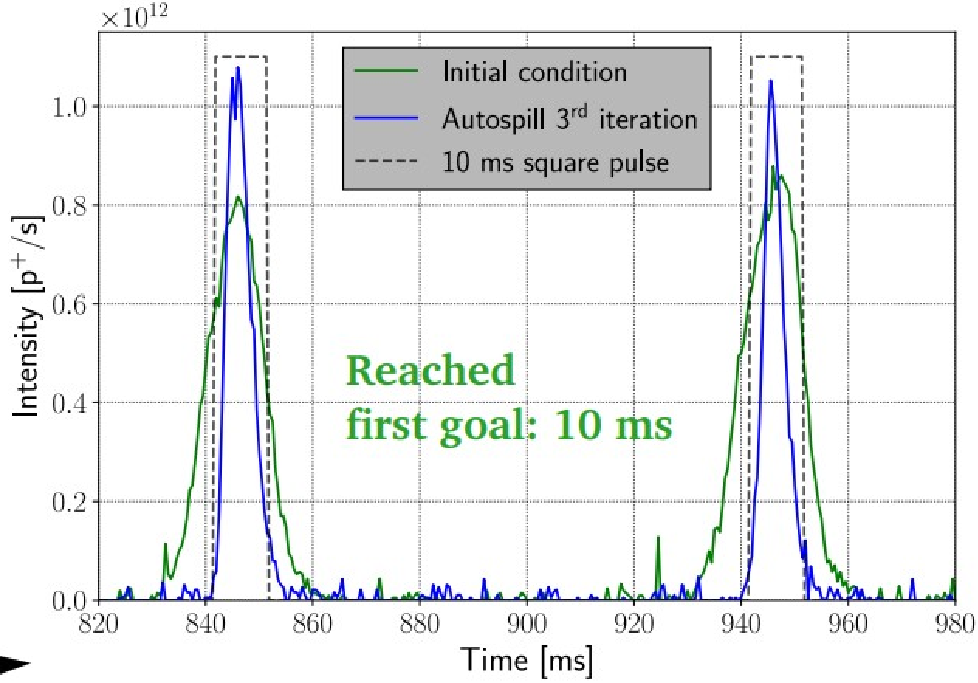
Proton extraction R&D for horn focusing

CERN-TE-ABT-BTP, BE-OP-SPS
Velotti, Pari, Kain, Goddard

before LS2: burst mode slow extraction achieved at the SPS. Iterative feedback tuning allowed to reach ~10 ms pulses without introducing losses at septa





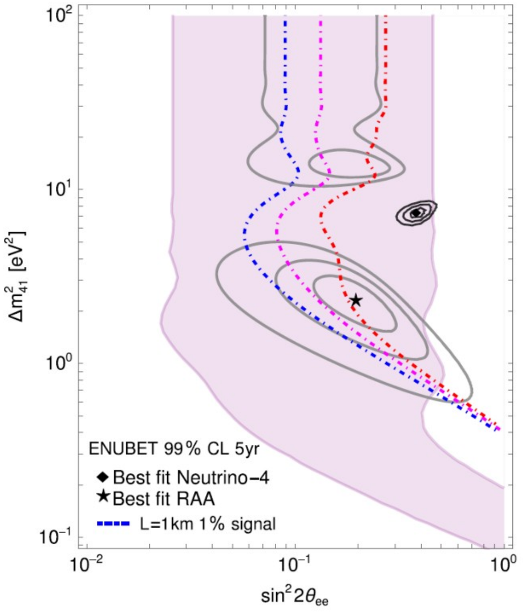


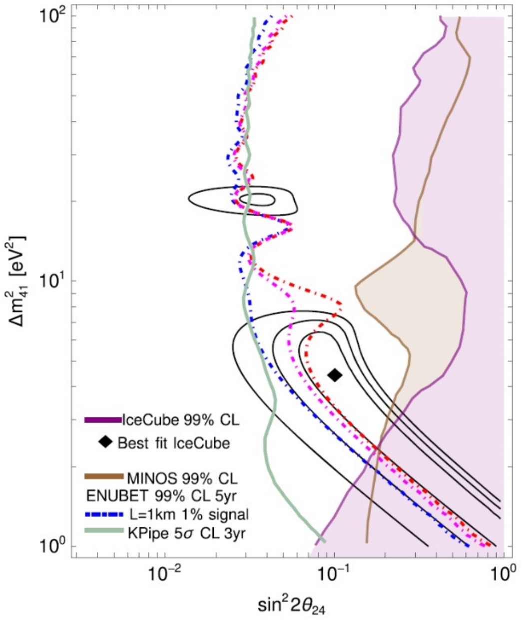
PhD thesis of M. Pari (UniPD + CERN doctoral). Defended 23/2/21.

BSM

Sterile neutrinos: some results already available

L.A. Delgadillo, P. Huber, PRD 103 (2021) 035018





Instrumented proton and hadron dump:

P. S. Bhupal Dev, Doojin Kim, K. Sinha, Yongchao Zhang, Phys. Rev. D 104, 035037 [ALP]
J. Spitz, Phys. Rev. D 89 (2014) 073007 [KDAR]

Work ongoing for studies of **Dark Sector** and **non-standard neutrino interactions** to assess potential of SBL versus Near detectors:

- Pros: energy control of the incoming flux. Outstanding precision on flux and flavor
- Cons: limited statistics

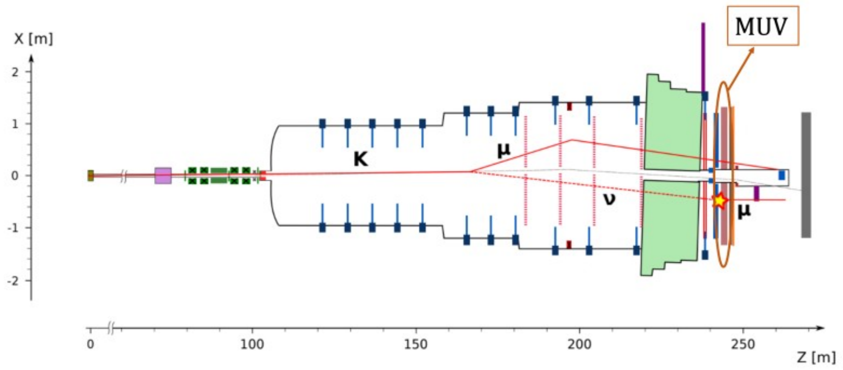
For the first time at nufact2023

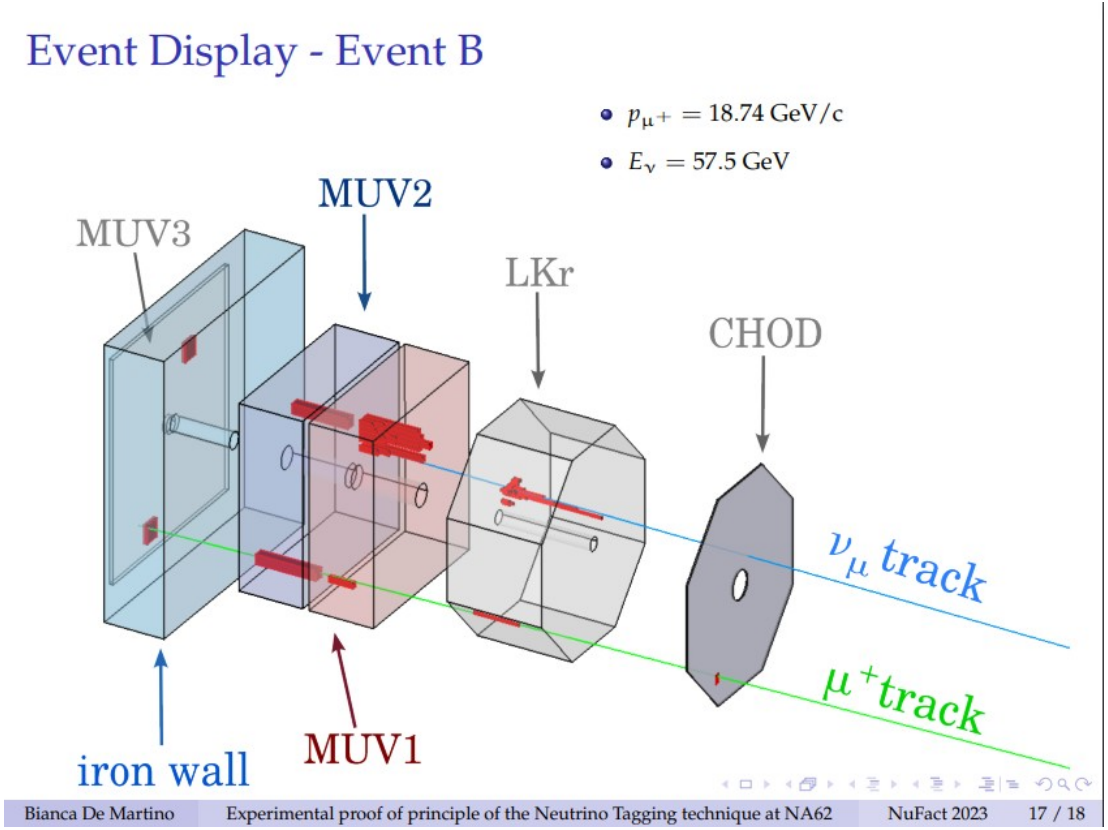
https://indico.cern.ch/event/1216905/contributions/5448754/attachments/2702123/4690877/NuFACT_NuTagging_DeMartino.pdf

Bianca De Martino (NA62)

S/B=5.5, 2 candidates

Muon from K decay + neutrino interaction in Xe calorimeter in an existing experiment!





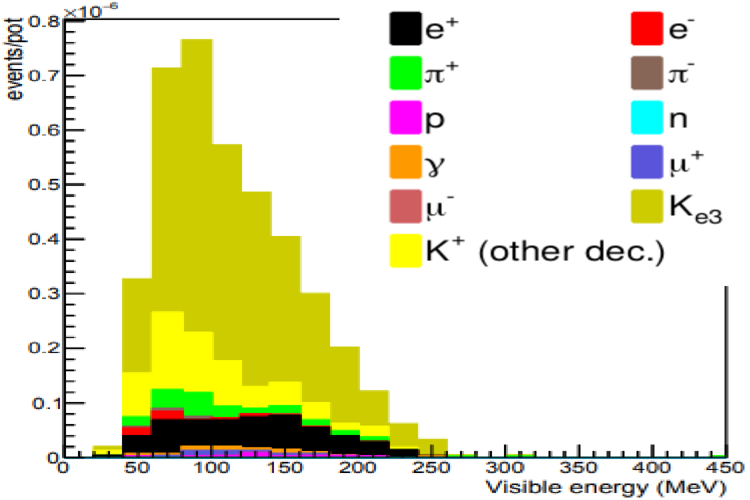
Lepton reconstruction

F. Pupilli et al., PoS NuFact2021 (2022) 025
https://arxiv.org/pdf/2308.09402.pdf

GEANT4 simulation. Event building: clustering of cells in space and time (accounting for **pile-up**) → PID with a Multilayer Perceptron

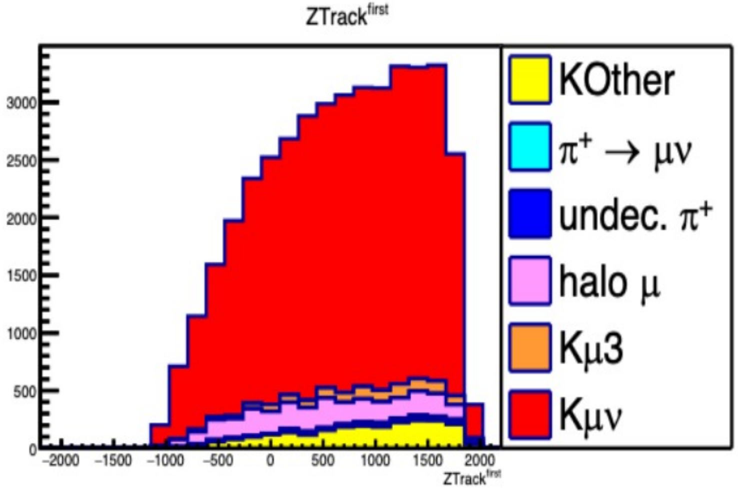
Half of efficiency loss is geometrical

K_{e3} eff. ~22% S/N ~2



e^+ candidate visible energy (MeV)

$K_{\mu2}$ eff. 34% S/N ~ 6
$K_{\mu3}$ eff. 21% ($K_{\mu3}$) S/N ~ 6



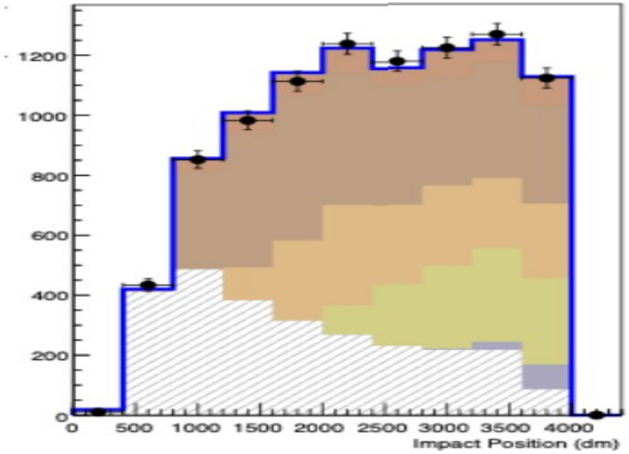
μ^+ candidate z coord (cm)

Constraint from lepton rates → flux systematics reduction

- Build S+B model to fit lepton observables
  - 2D distributions in z(lepton) and reconstructed-energy
- include hadro-production (HP), transfer line (TL), detector systematics as nuisance parameters (α, β, …)

$$L(N|N_{exp}) = P(N \mid N_{exp}) \cdot \prod_{bins} P(N_i \mid PDF_{Ext.}(N_{exp}, \vec{\alpha}, \vec{\beta})_i) \cdot pdf_{\alpha}(\vec{\alpha} \mid 0,1) \cdot pdf_{\beta}(\vec{\beta} \mid 0,1)$$

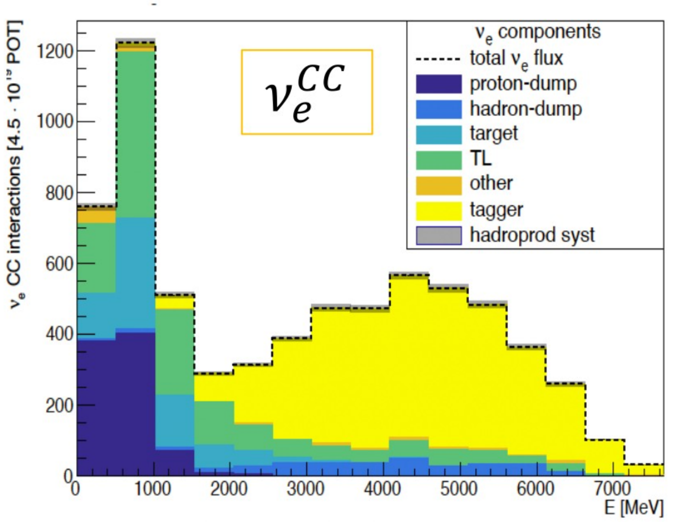
→ Extended Maximum Likelihood fit

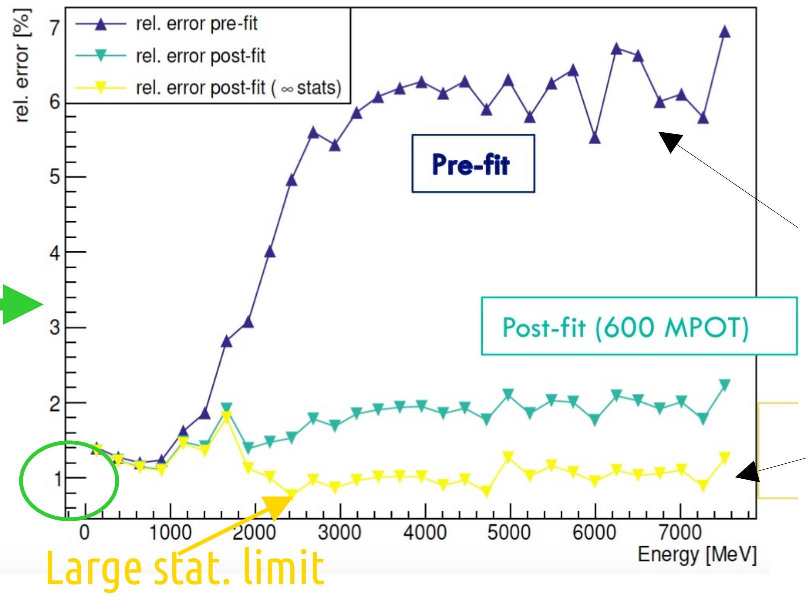


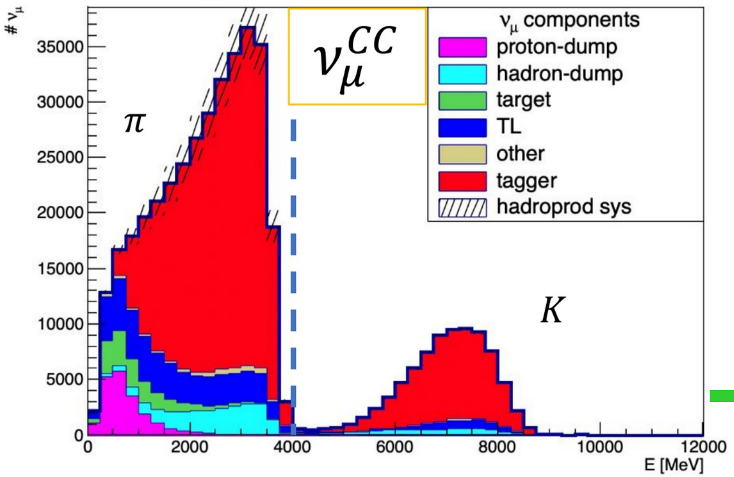
Each histogram component corresponds to a bin in E_ν

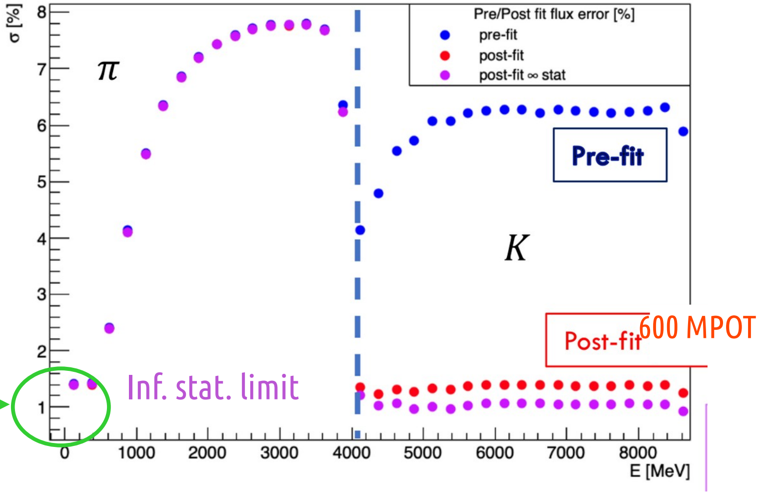
Use a parametric model fitted to hadro-production data from **NA56/SPY experiment**:
- compute variations ("envelopes") using multi-universe method ("toy exp") for the lepton observables and the flux of neutrinos
- evaluate "post-fit" variance of the expected flux

Flux constraint results









Before constraint:

sys. budget from HP (NA56/SPY data): **~6%**

After constraint (fit to lepton rates measured by the tagger):
Down to **~1%** !

Full simulation data (beamline, detector, reconstruction)

Works for both ν_e and ν_μ

Finalizing the analysis to include detector effects, publication in preparation

Tagger particle budget at true level