A future ν cross section facility with NP06/ENUBET

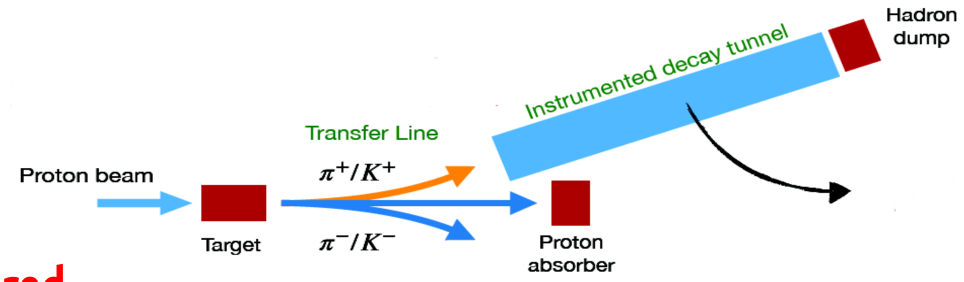
A. Longhin
Padova Univ. and INFN
on behalf of the ENUBET Coll.

Outline

- Summary of achievements, new studies
- Towards an implementation proposal: new directions within "Physics Beyond Colliders"

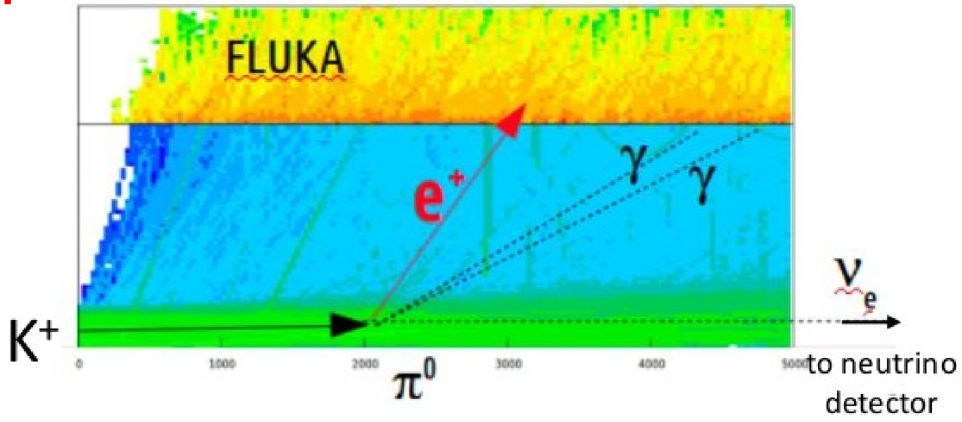
Monitored neutrino beams

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



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

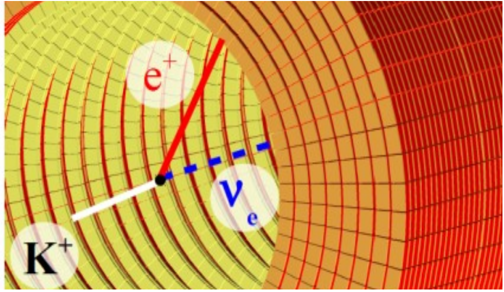
- **Instrumented decay region**
  $K^+ \rightarrow e^+ \nu_e \pi^0 \rightarrow$ (large angle) e^+
  $K^+ \rightarrow \mu^+ \nu_\mu \pi^0$ or $\rightarrow \mu^+ \nu_\mu \rightarrow$ (large angle) μ^+
- **ν_e and ν_μ flux prediction from e^+/μ^+ rates**



- Needs a **collimated momentum-selected hadron beam** → only the decay products hit the tagger
  → manageable rates and irradiation in the detectors
- Needs a **"short", 40 m, 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!)

Project 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**

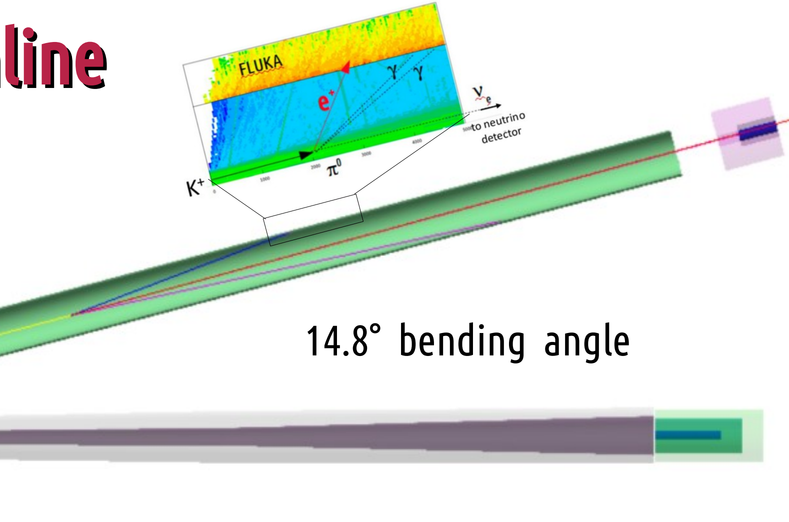
- CERN Neutrino Platform: NP06/ENUBET
- Physics Beyond Colliders

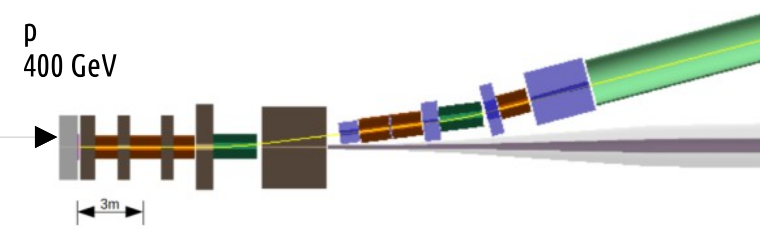
Present collaboration: 74 auth, 17 institutions

The ENUBET hadron beamline

EPJ-C 83, 964, (2023)

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





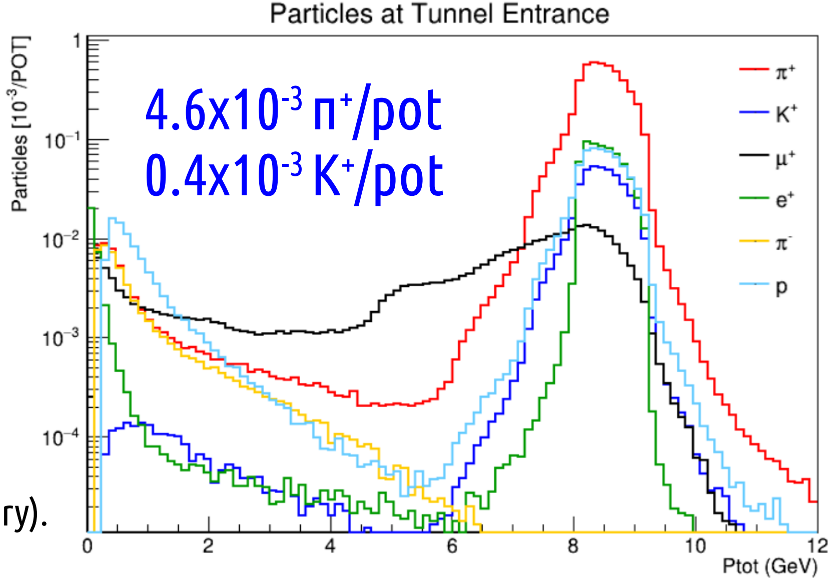
Design and performance of the ENUBET monitored neutrino beam

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

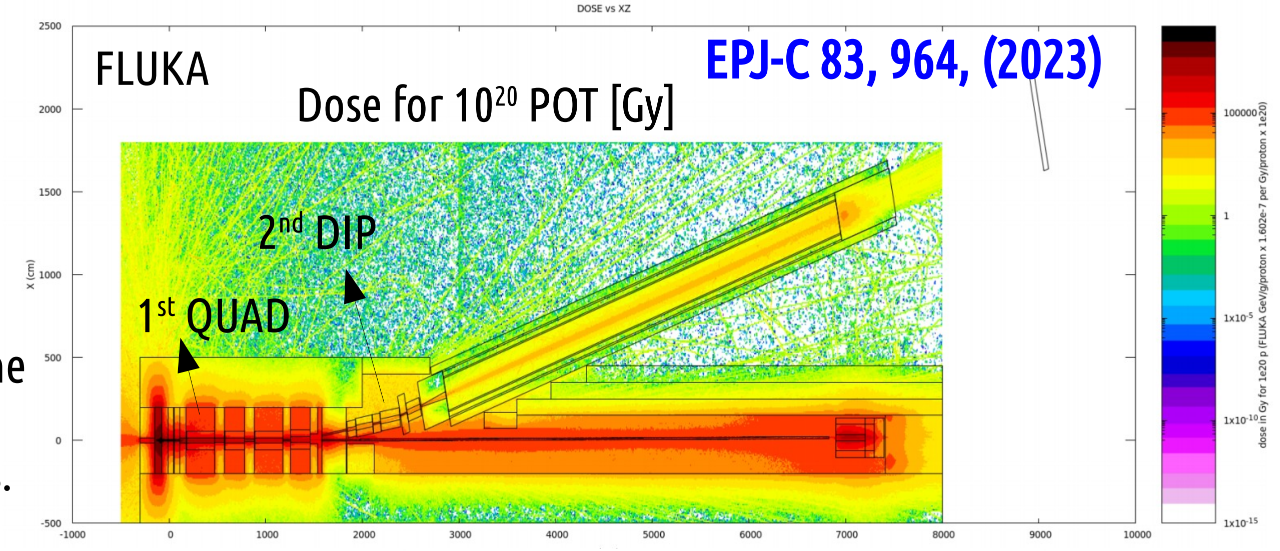
- **The baseline design has been documented in EPJ-C 83, 964, 2023**
  - Uses existing standard (warm) magnets
  - Focuses **8.5 GeV +/- 10%** pions and kaons (drives the ν spectrum!)
  - Target: graphite L = 70 cm, r = 3 cm (optimized)
  - W foil: downstream of target to absorb background from e^+
  - Inermet optimized absorber @ tagger entrance
  - p-dump: three cyl. layers (graphite core → aluminum → iron)
  - H-dump: ~ p-dump to reduce back-scattering in the tunnel
  - Simulation: optics optimization (TRANSPORT).
  - Particle transport, interactions: G4beamline.
  - Irradiation (FLUKA). Systematics (GEANT4, fully parametric, access to particle history).

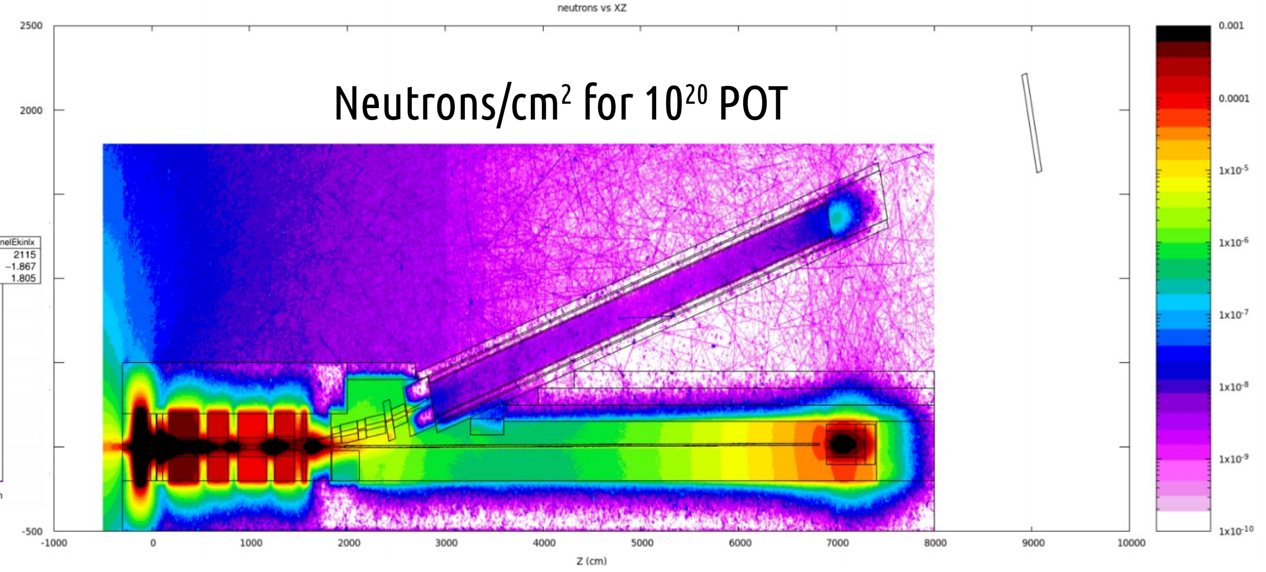


Irradiation/detectors

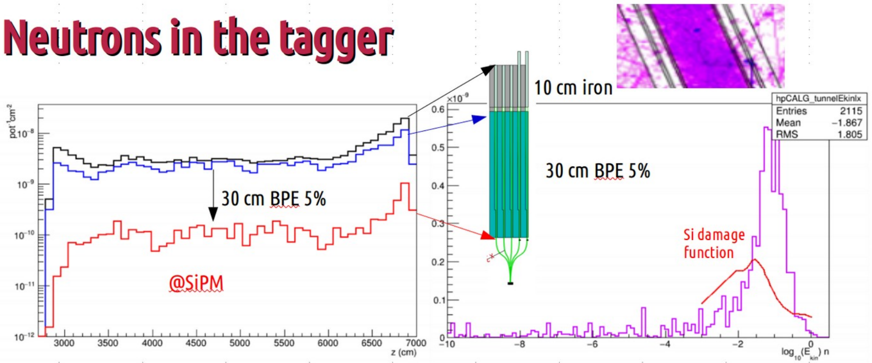
Dose is sustainable by magnets even in the hottest regions (<300 kGy/10^{20} pot).

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

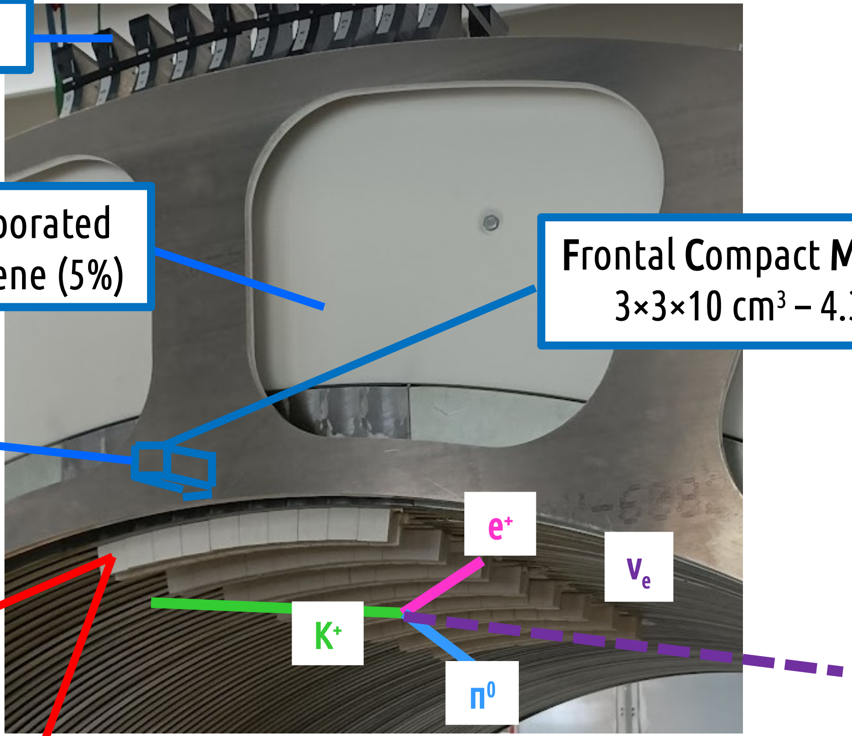


The lepton tagger

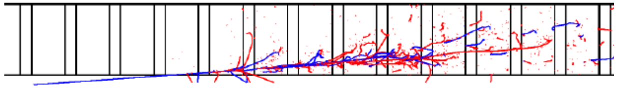
Light r/o (SiPM)

30 cm of borated polyethylene (5%)

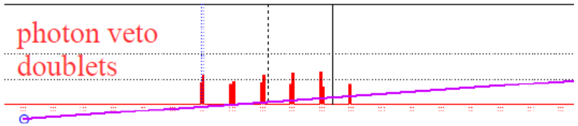
Frontal Compact Module
$3\times3\times10$ cm^3 – 4.3 X_0

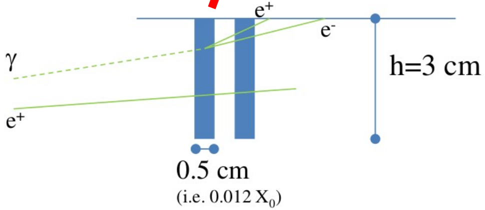


Calorimeter
Longitudinal segmentation
Plastic scintillator + Iron absorbers
Integrated light readout with SiPM
→ $e^+/\pi^\pm/\mu$ separation



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





e^+ (signal) topology

π^0 (background) topology

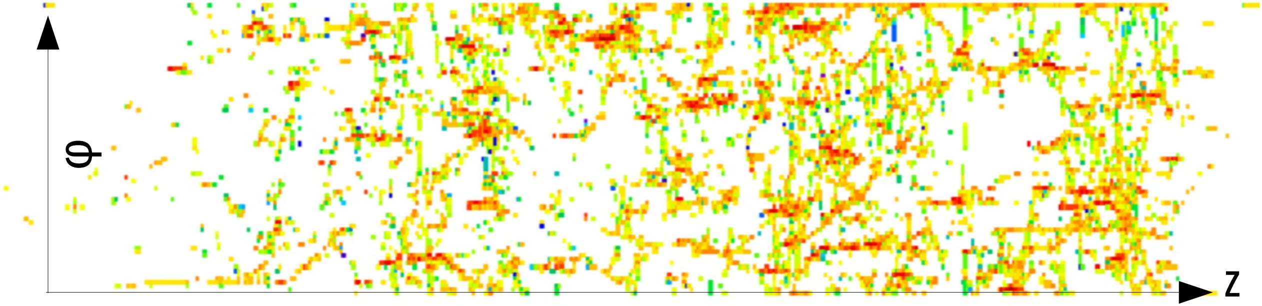
π^+ (background) topology

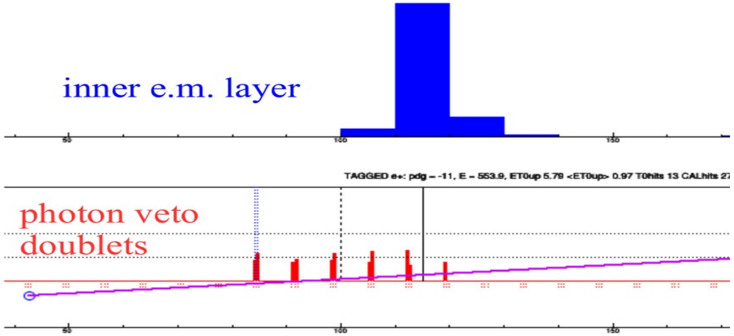
Lepton reconstruction in the tagger

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

GEANT4 simulation of the detector, validated by prototype tests at CERN
Event building: clustering of cells in space and time (accounting for **pile-up**) → PID with a Multilayer Perceptron.

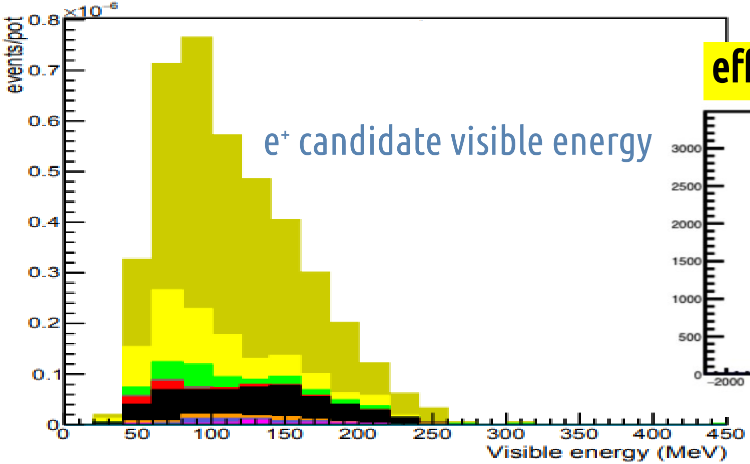
Hit map for e^+



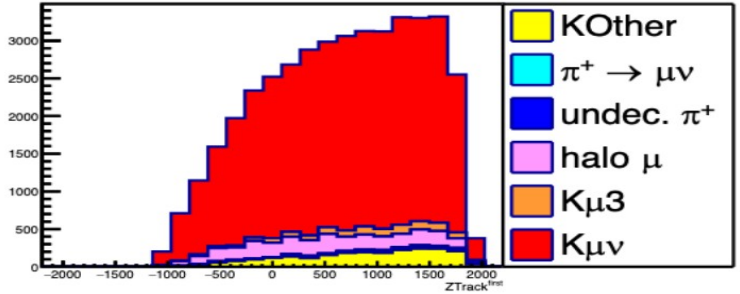


K_{e3} e+: efficiency ~22%, S/N of ~2

Half of efficiency loss is geometrical



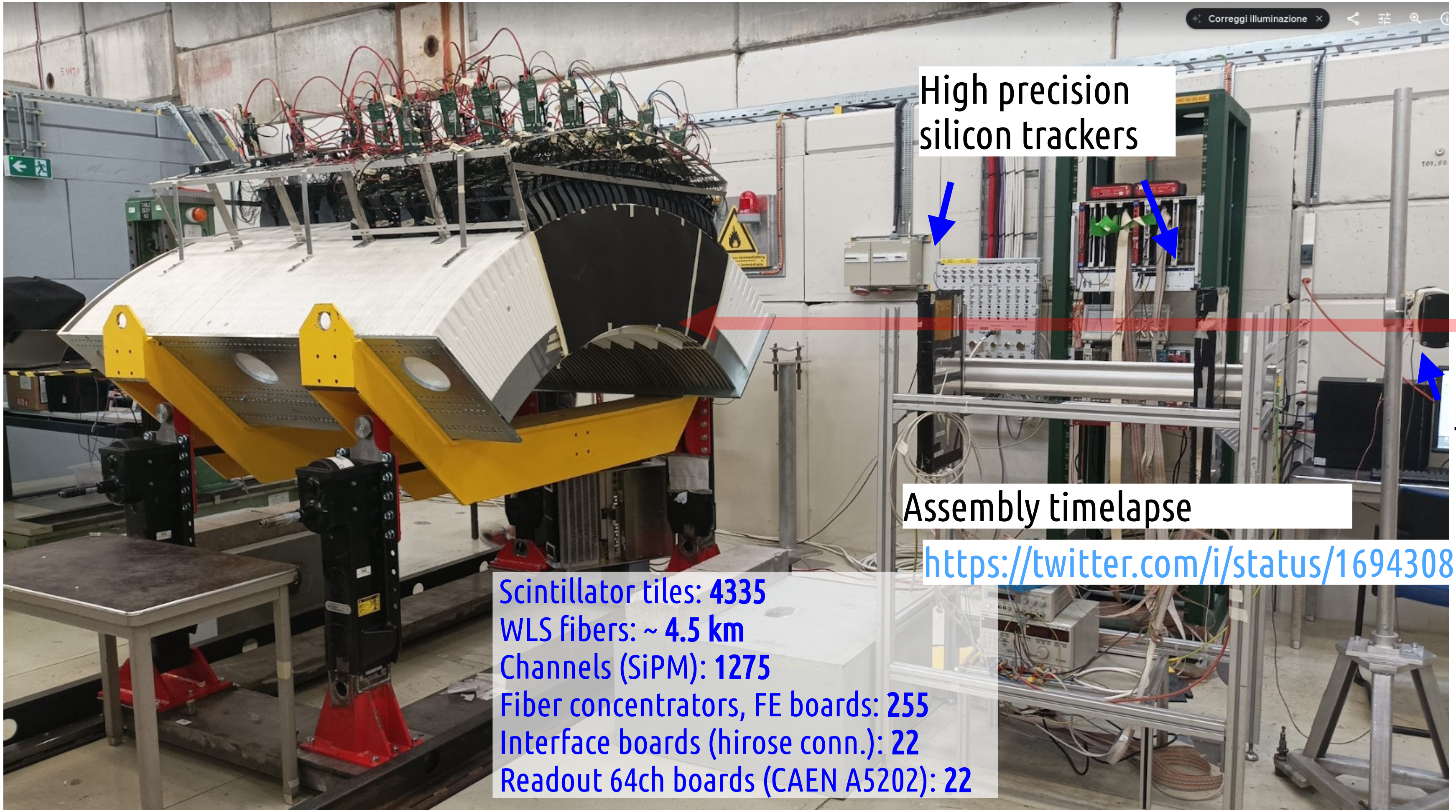
efficiency 34% ($K_{\mu 2}$) and 21% ($K_{\mu 3}$) S/B ~ 6.1



μ^+ candidate z coord (cm)

The ENUBET tagger demonstrator

August 2023 CERN-PS-T9



High precision silicon trackers

e, π, μ (0.5-15 GeV)

Trigger scint.

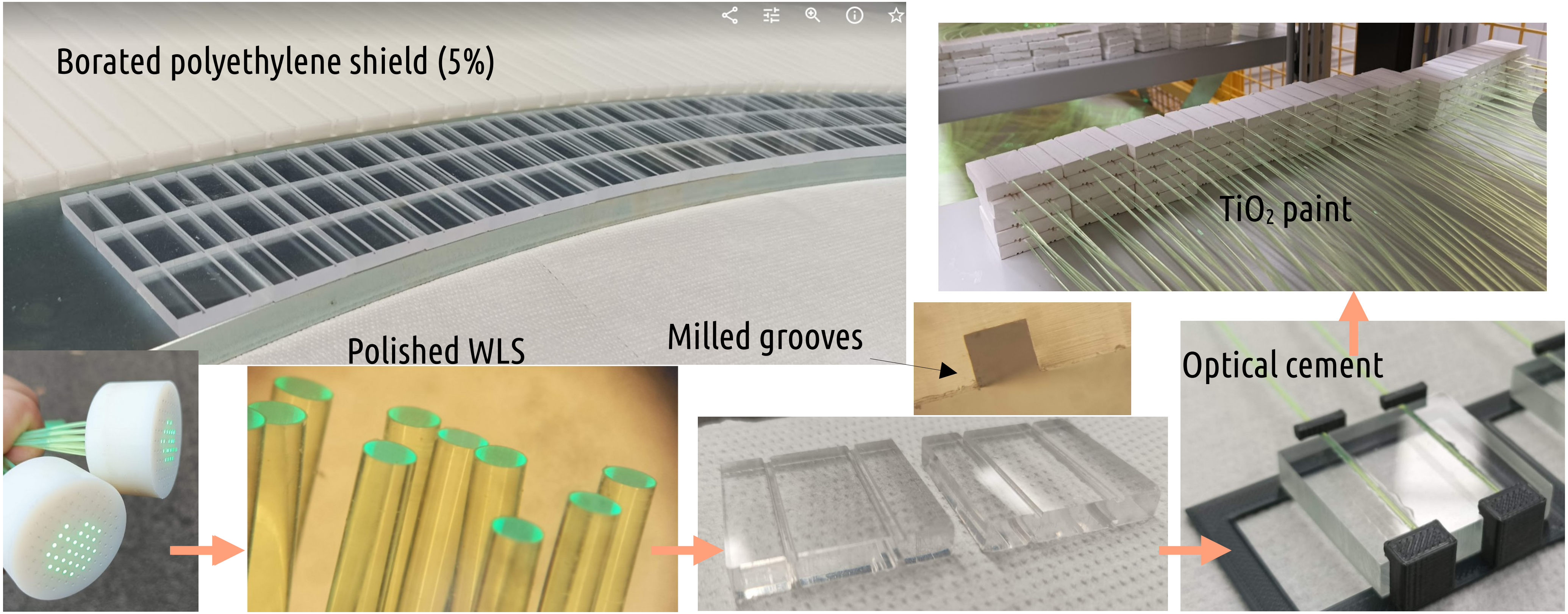
Assembly timelapse

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

Scintillator tiles: **4335**
WLS fibers: ~ **4.5 km**
Channels (SiPM): **1275**
Fiber concentrators, FE boards: **255**
Interface boards (hirose conn.): **22**
Readout 64ch boards (CAEN A5202): **22**

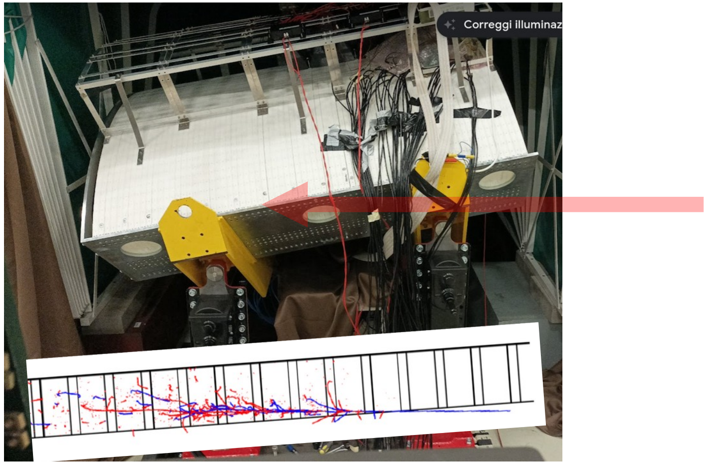
The demonstrator detector technology

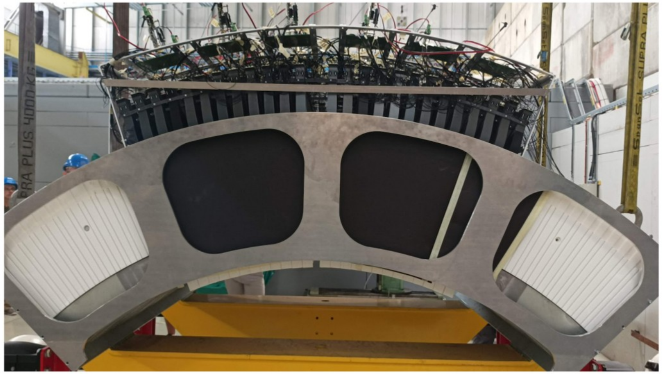
Commercial scintillator slabs + cutting/milling in Italy. Polishing, fiber gluing, tiles painting **with personnel from the collaboration @ INFN-LNL**



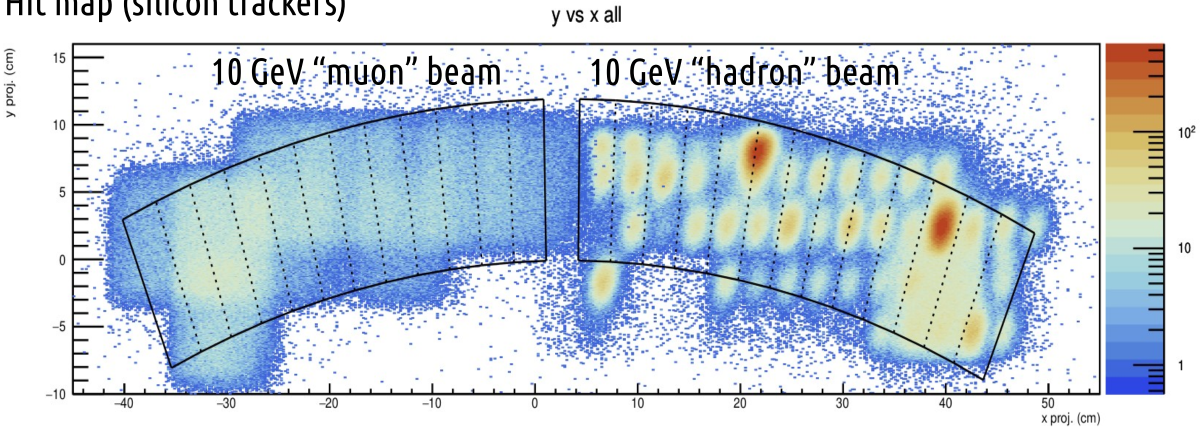
Examples: inclined and calibration runs

200 mrad tilt run

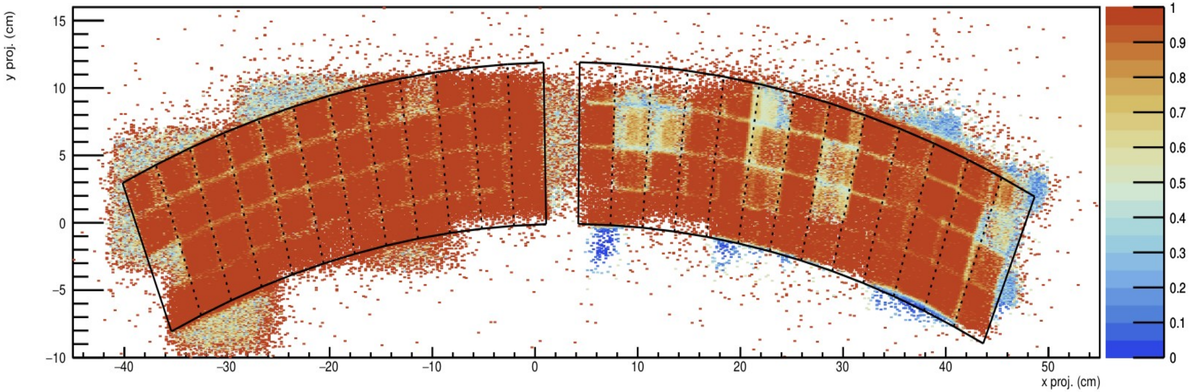




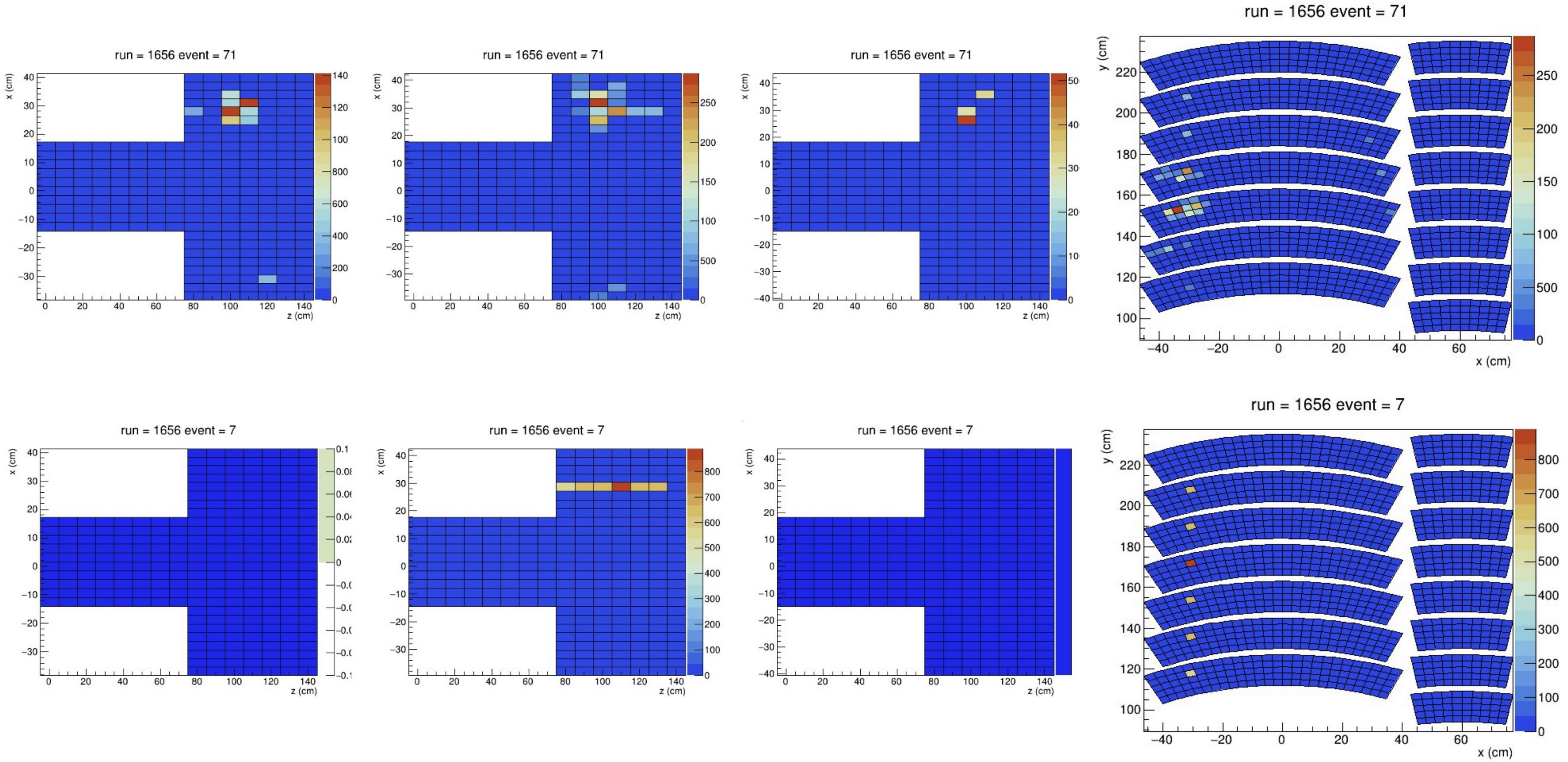
Hit map (silicon trackers)



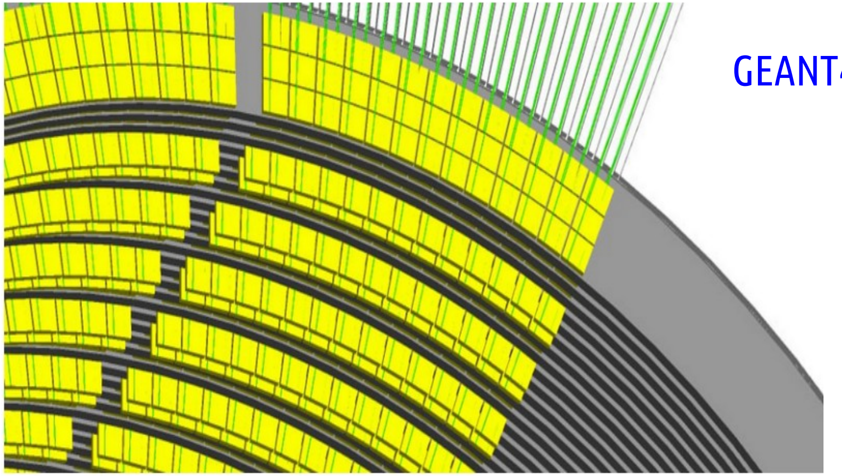
Efficiency map



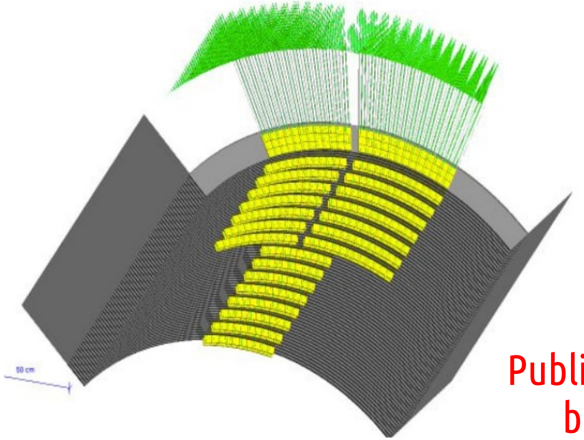
Event display (10 GeV hadrons and muons)

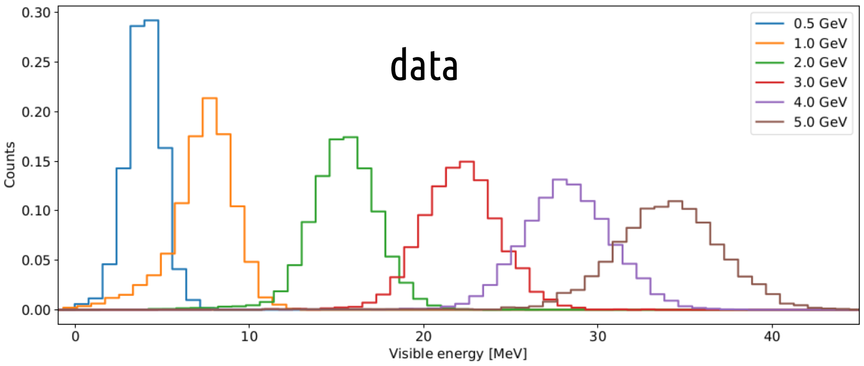


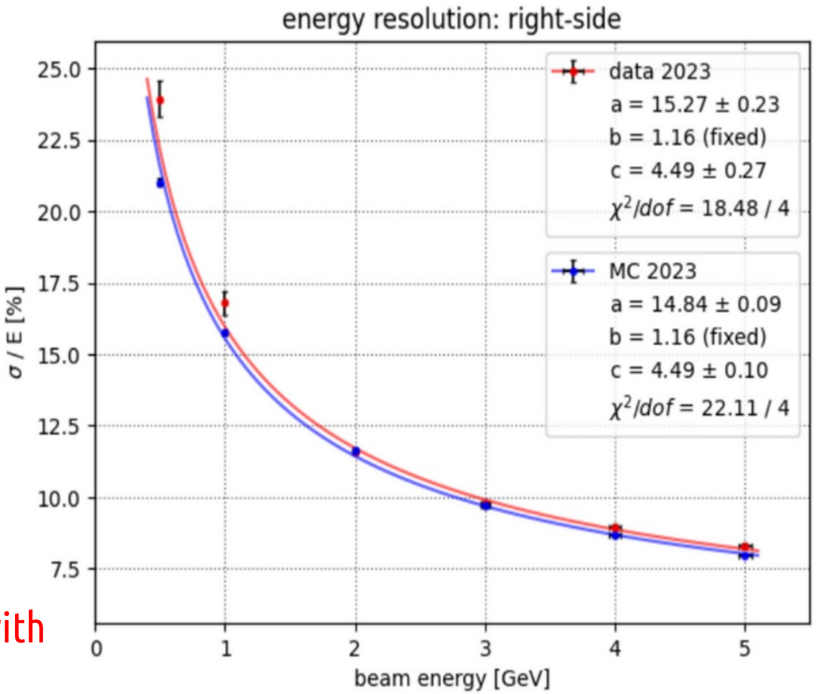
Electron energy resolution



GEANT4



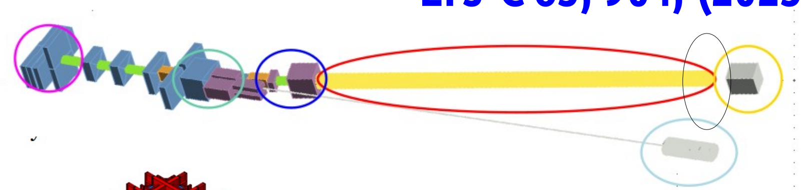




Publication in the pipeline with both 2022 and 2023 data

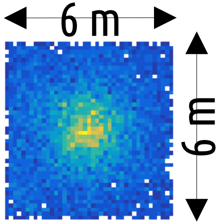
ν_μ^{CC} spectra at detector

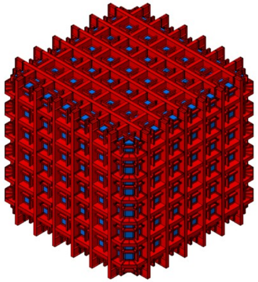
EPJ-C 83, 964, (2023)



500t @ 50 m after the hadron dump
@ 400 GeV → **0.7 Mν_μ^{CC}** with 1e20 POT

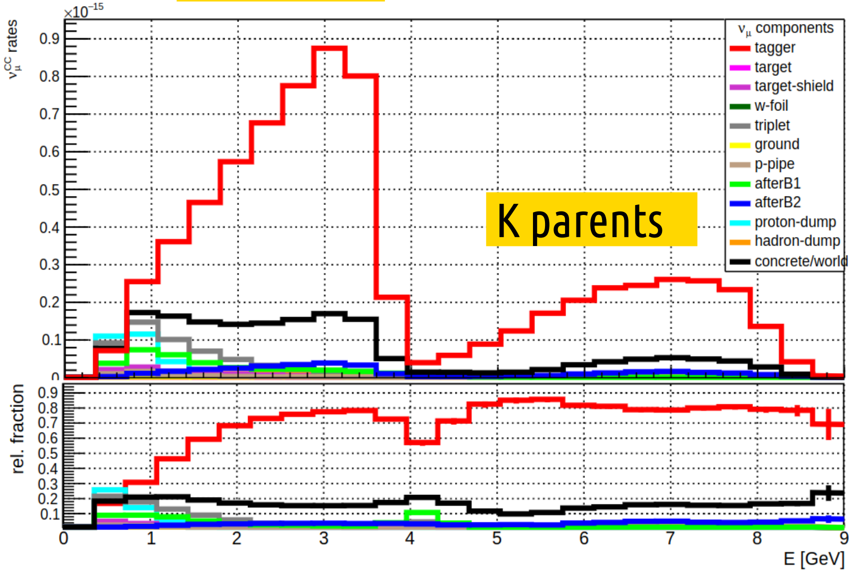
→ **10000 ν_e^{CC}** with ~1e20 POT

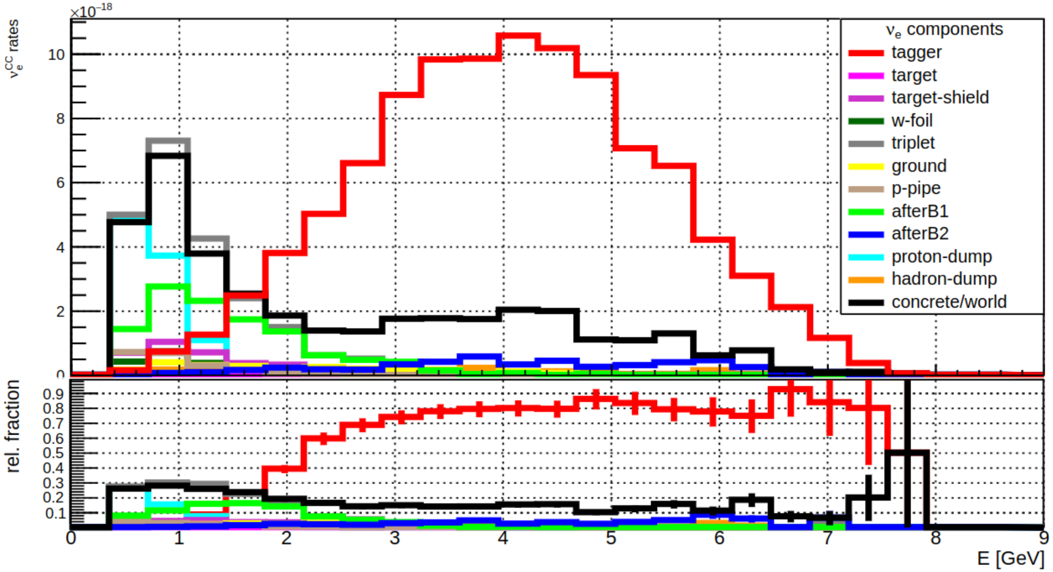




The protoDUNE(s) could be such a detector (an evident asset for a possible siting at CERN)

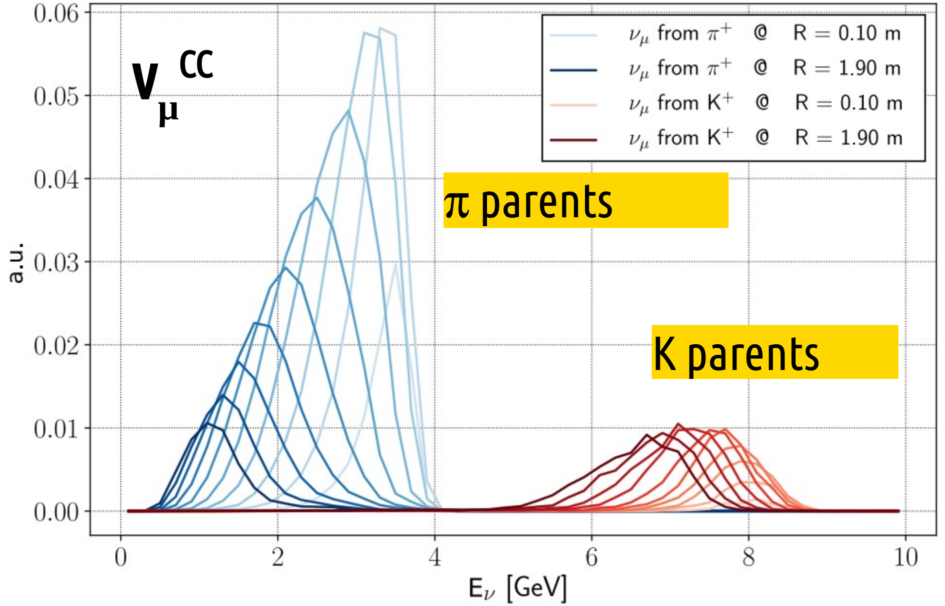
π parents

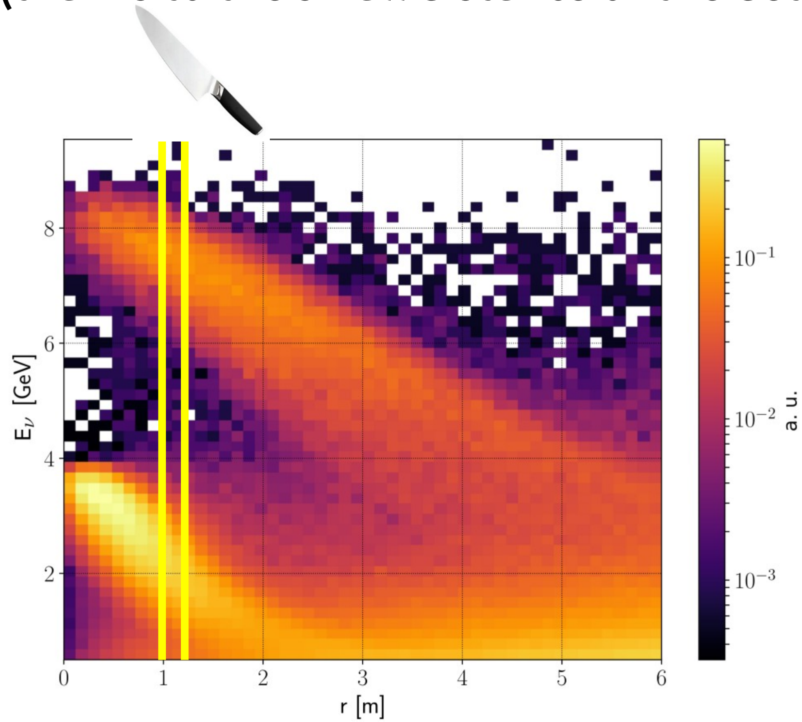




ν_μ fluxes decomposition: NBOA (~PRISM)

"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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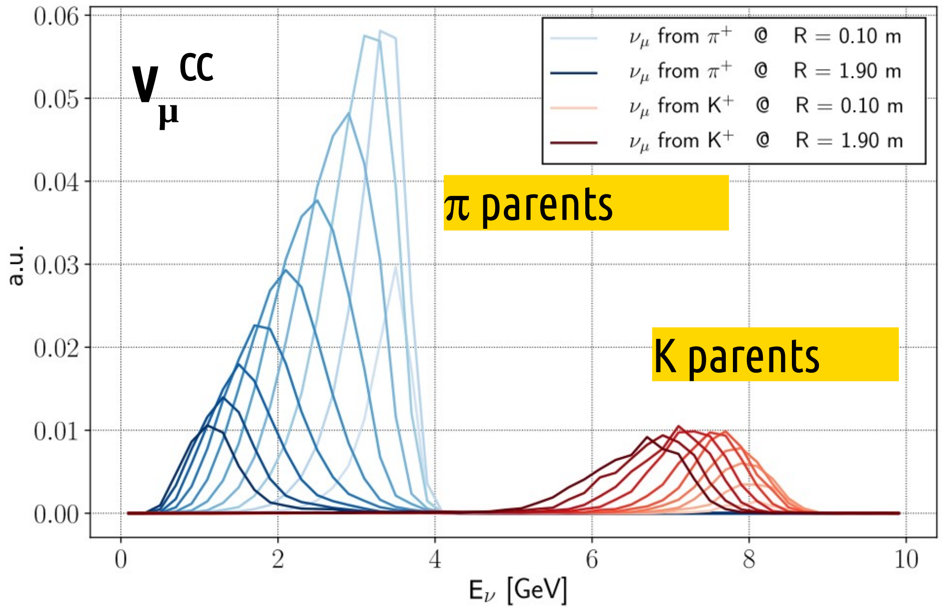
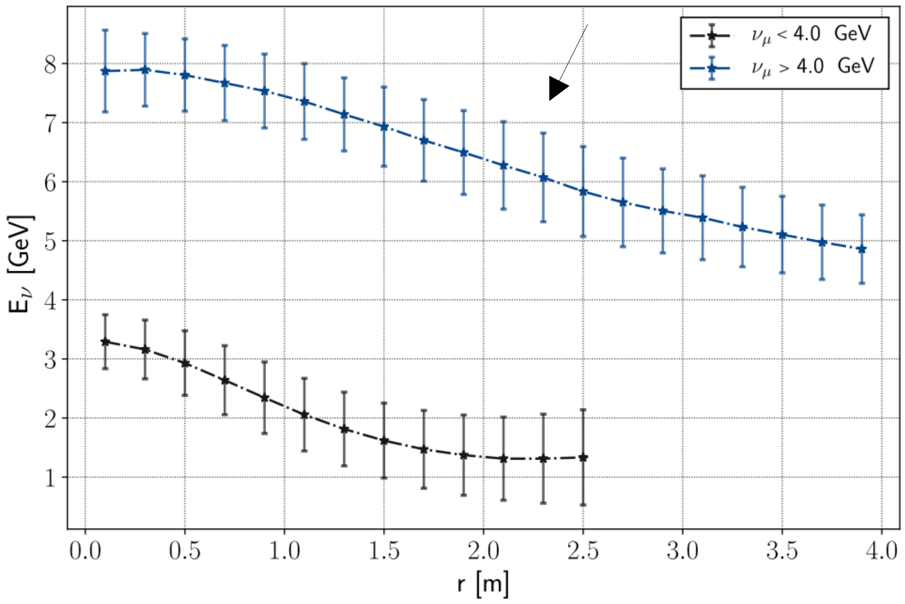
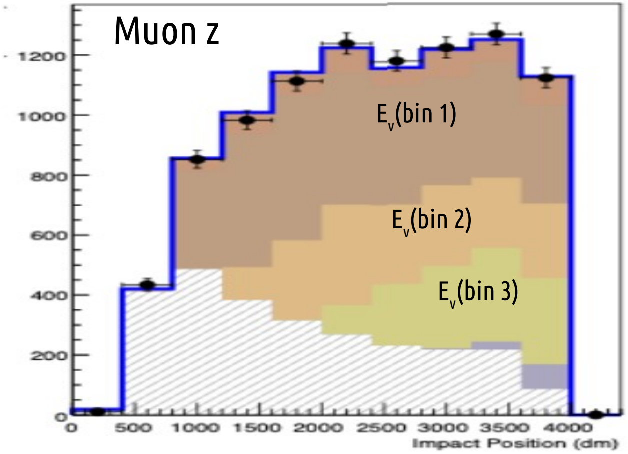


Error bands visualize the rms of the energy distributions



Flux constraint from lepton rates → systematics reduction



Each histogram component corresponds to a bin in E_ν

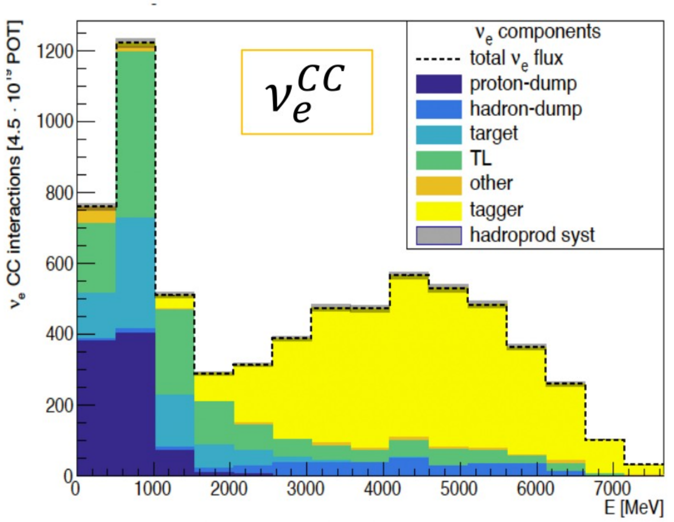
- Build S+B model to fit lepton observables
  - 2D distributions in z(lepton) and reconstructed-energy
- include hadro-production (HP), transfer line (TL), detector systematics as nuisance parameters (α, β, ...)

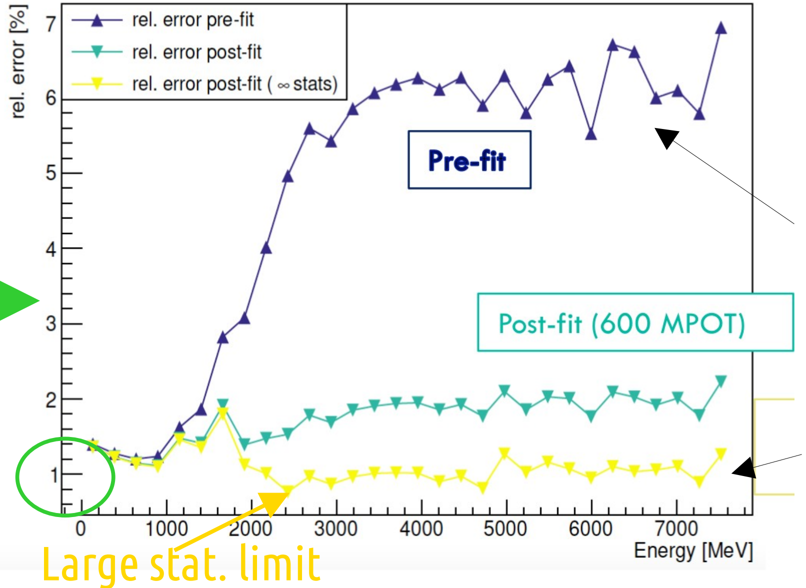
$$L(N|N_{exp}) = P(N \mid N_{exp}) \cdot \prod_{bins} P(N_i \mid PDF_{Ext.}(N_{exp}, \vec{\alpha}, \vec{\beta})_i) \cdot pdf_\alpha(\vec{\alpha} \mid 0,1) \cdot pdf_\beta(\vec{\beta} \mid 0,1)$$

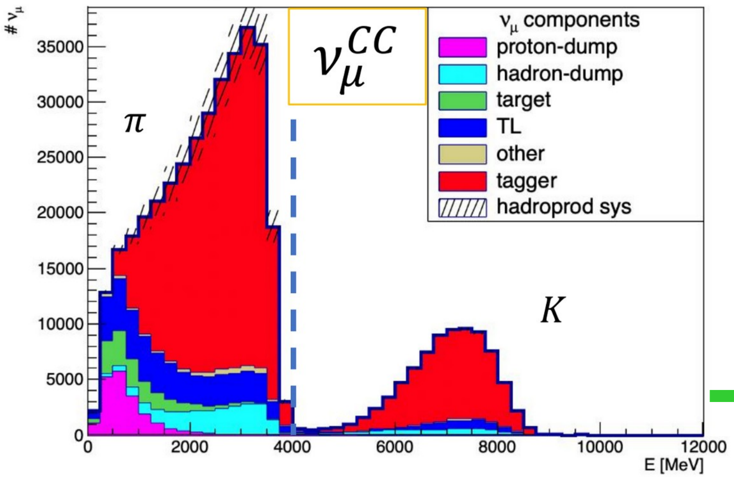
→ Extended Maximum Likelihood fit

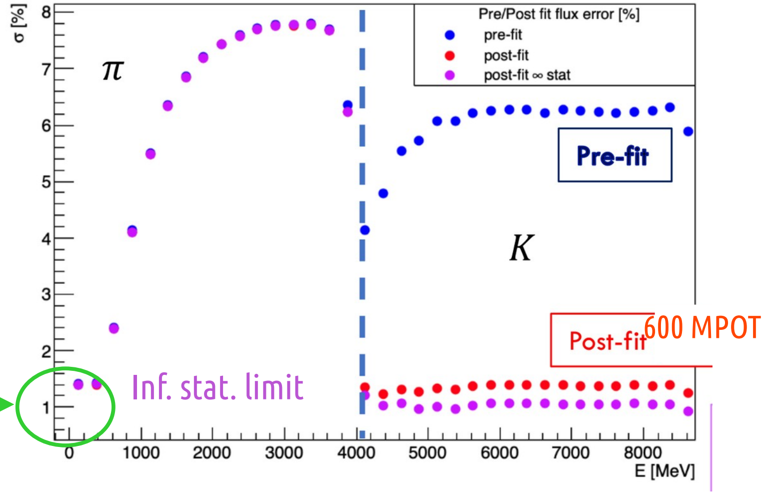
Use a parametric model fitted to hadro-production data from **NA56/SPY experiment**:
- compute variations (“envelopes”) using multi-universe method (“toy exp”) for the lepton observables and the flux of neutrinos
- evaluate “post-fit” variance of the expected flux

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

ENUBET & time-tagging

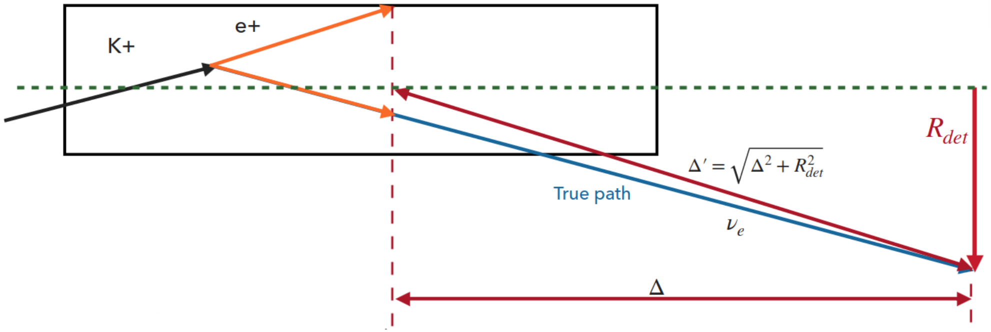
EPJ-C 83, 964, (2023)

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).

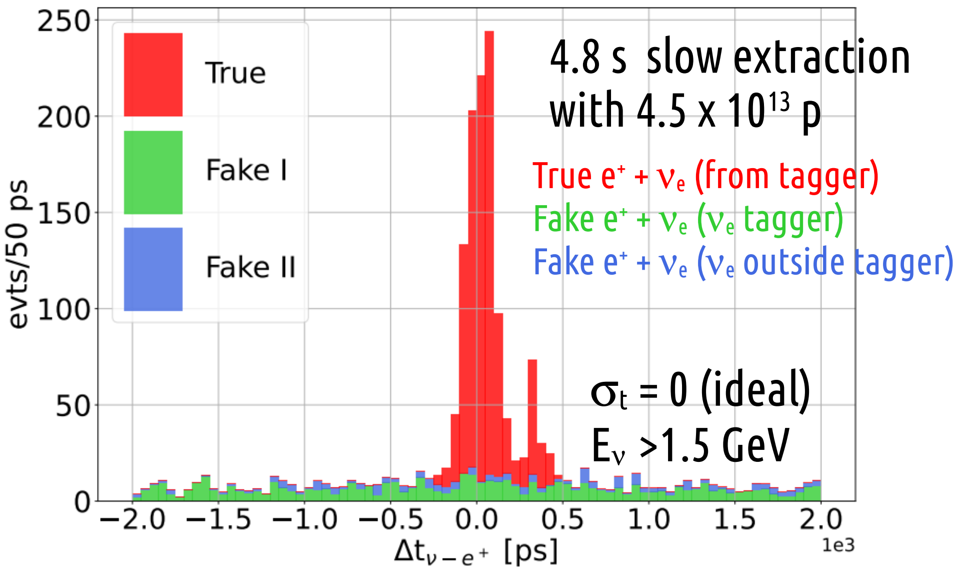
In the last EPJ paper we studied the time correlation btw K_{e3} e^+ and ν_e candidates with the full simulation (reconstruction, backgrounds) →

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



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

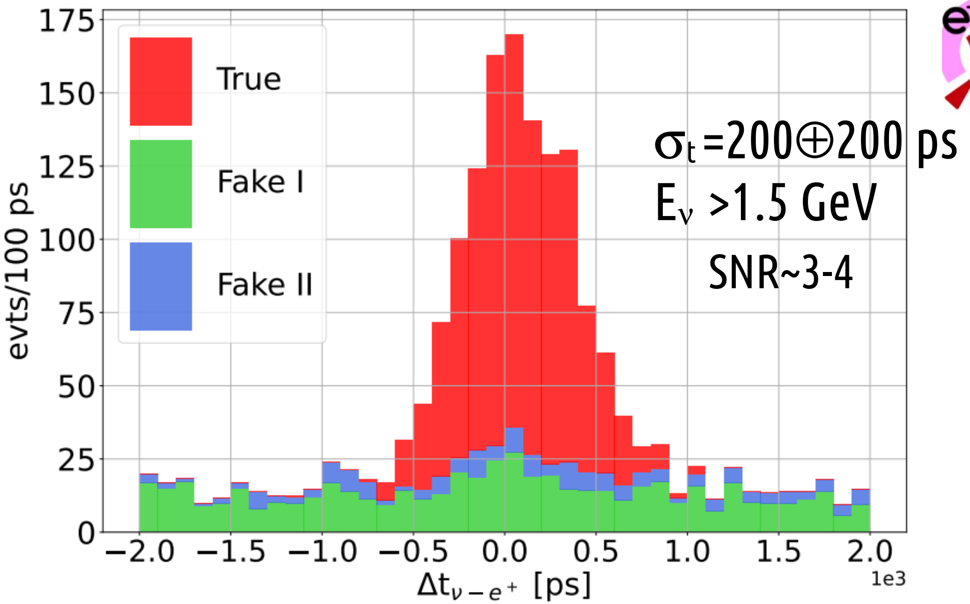


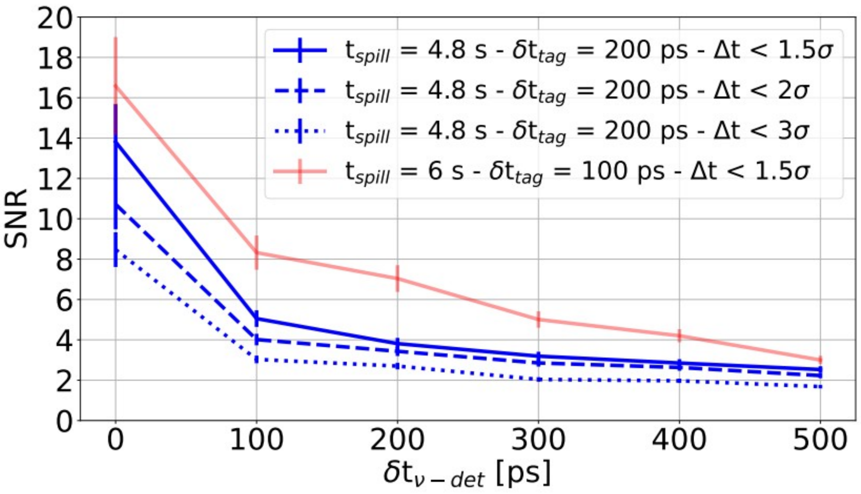
ENUBET & time-tagging

EPJ-C 83, 964, (2023)

We can exploit the **time coincidences** to improve the purity of the sample of associated positrons for the subsample of the decays in which a neutrino is actually observed.

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 16 (depending on the assumptions on the timing resolutions of the tagger and neutrino detector and the slow extraction spill duration)

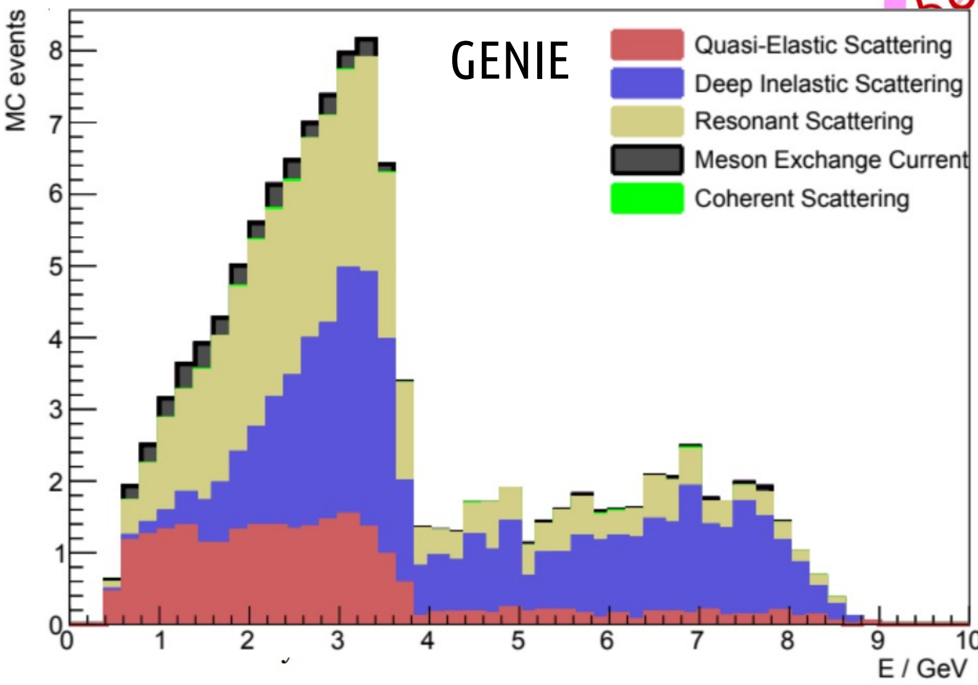


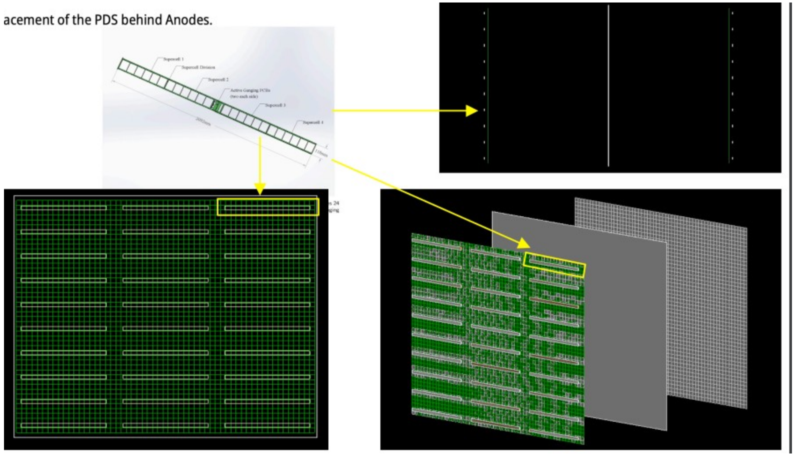


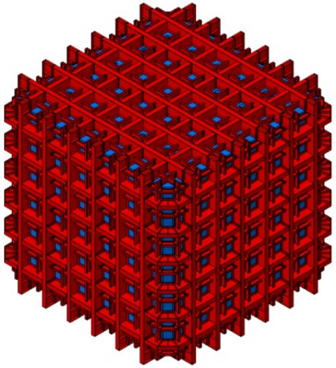
ν detector studies (ENUDET)

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**

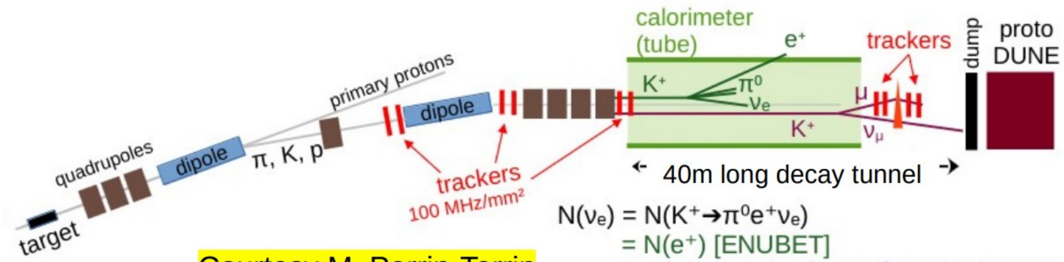






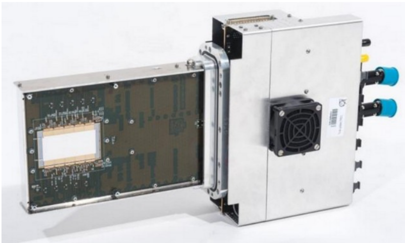
NUTAG: pushing on σ_t(tagger) and $\sigma(E_\nu)$

A. Baratto-Roldan et al.
arXiv: 2401.17068



Courtesy M. Perrin-Terrin

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



NuTag: proof-of-concept study for a long-baseline neutrino beam

A. Baratto-Roldán[1a], M. Perrin-Terrin[2], E.G. Parozzi[1], M.A. Jebramcik[1], and N. Charitonidis[1]

[1] CERN, BE Department, Esplanade des Particules 1, Meyrin, 1211 Geneva 23, Switzerland
[2] Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France

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

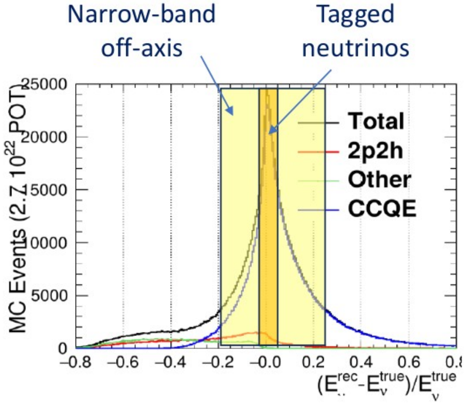
NP06/ENUBET can associate **decay leptons** on an event by event basis.
NUTAG: use state-of-the-art silicon trackers with excellent timing ("4D") to also **tag the parent of the decay**

Ideally suited 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 ProtoDUNE or WCTE)

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

Almost all ν_μ and $\bar{\nu}_\mu$ from 2-body dec. of π, K → large 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 in detector. Relax time matching criteria.



Challenging! Could provide E_ν resolutions at the % level.
Work in progress towards a common ENUBET+NUTAG facility (→ PBC)

The PBC-SBN study group

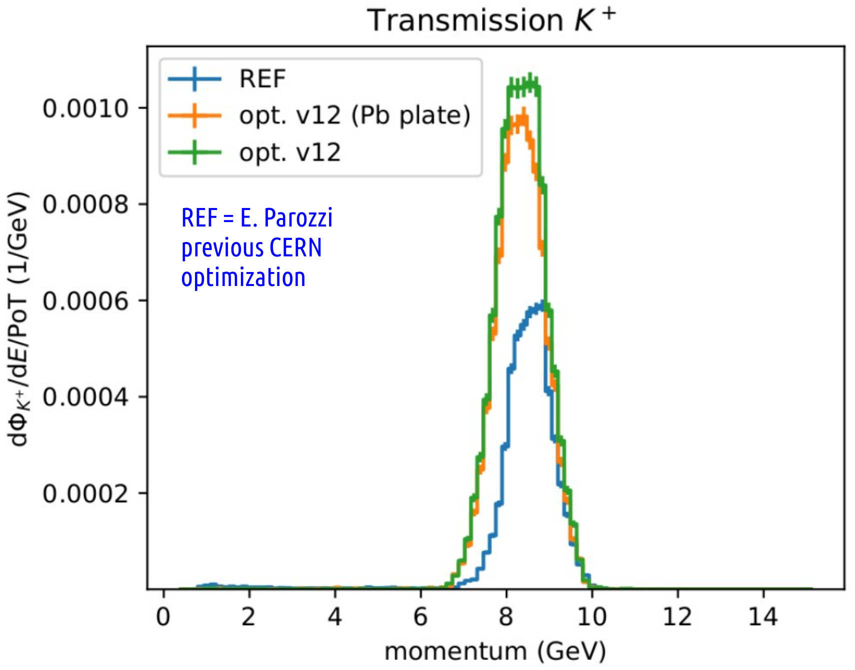
CERN Physics Beyond Colliders – short baseline neutrino (PBC-SBN) started in full swing in 2023 Inspired by the achievements of NP06/ENUBET. It **enhances its physics reach** by addressing:

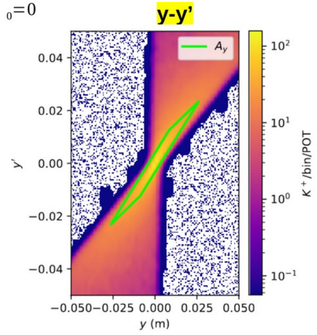
- A conceptual level feasibility study: possible locations at CERN, constraints, costs
  → a beamline **compatible with the CERN fixed target programme** (more ν with less p)?
- High-precision measurements of E_ν through meson tracking inside the beamline: **NUTAG**
  meson tracking using fast silicon trackers (NA62 and HL-LHC technologies) to enhance the energy resolution for ν_μ down to a few %, especially where NP06/ENUBET is less performing
- An extension of the monitored flux down to **O(1) GeV**

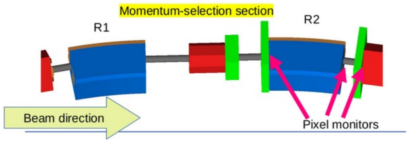
- These points motivated a **redesign of the beamline**:
  - more "**cost-effective**" in terms of proton economics.
  - flexible for focusing mesons lower that 8.5 GeV, with **regions at lower track density** where NUTAG trackers could be safely operated.
  - The ENUBET beamline was using existing North-Area magnets with apertures < 15 cm while for this new exercise it was decided to be less conservative and allow for slightly **more "ambitious" magnets** that could anyway pay off in terms of a shorter data taking.

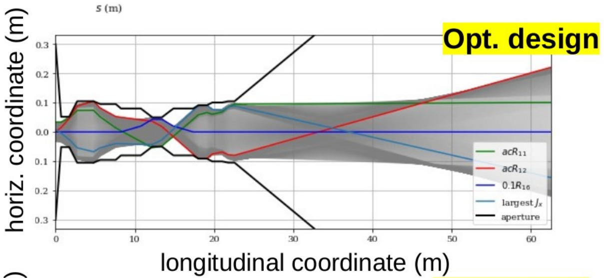
The PBC-SBN beamline optimization

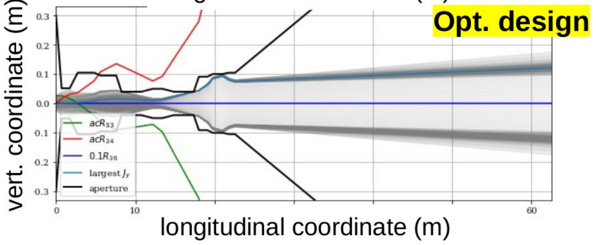
- link to the talk at the PBC annual meeting by M. Jebramcik 26/03/24
- Analyzed 16 targets, 7 drift spaces, 18 quad. parameters (6 magnets with different length, aperture, gradient) → **26 free parameters**
- **Multiple (3) objectives**: K+ & π+ transmission as possible and the beam size has to be as 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)**

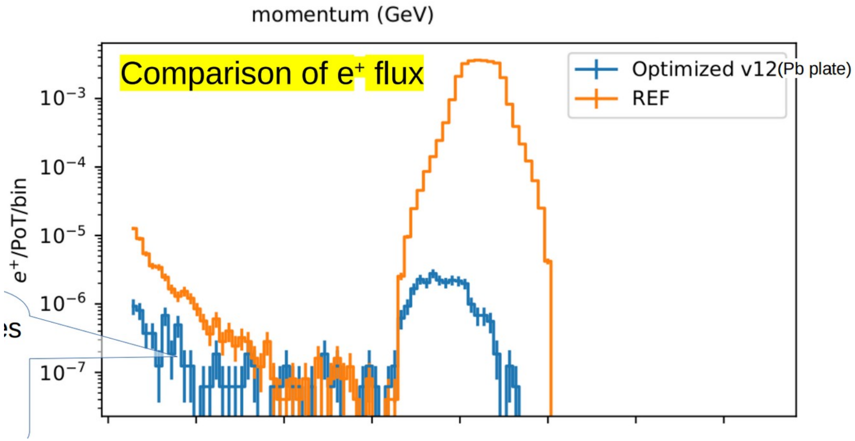












Conclusions and prospects

- Since our last NUINT in South Korea **lots improvements have happened**
- The results of ENUBET have been **consolidated**
  - **Beamline design → published**
  - **The demonstrator** has been completed (→ writing publication)
  - **Reduction of systematics works**! (working on publication)
- **Implementation** study at within **CERN-PBC**
  - ENUBET(+NUTAG) would be **a killer facility for cross sections**
  - Huge progress in terms of **reducing required protons** and simulation of the LAr **far detector**
  - Going towards a **robust proposal** within the **EU strategy timeline in 2025**

Valeu!

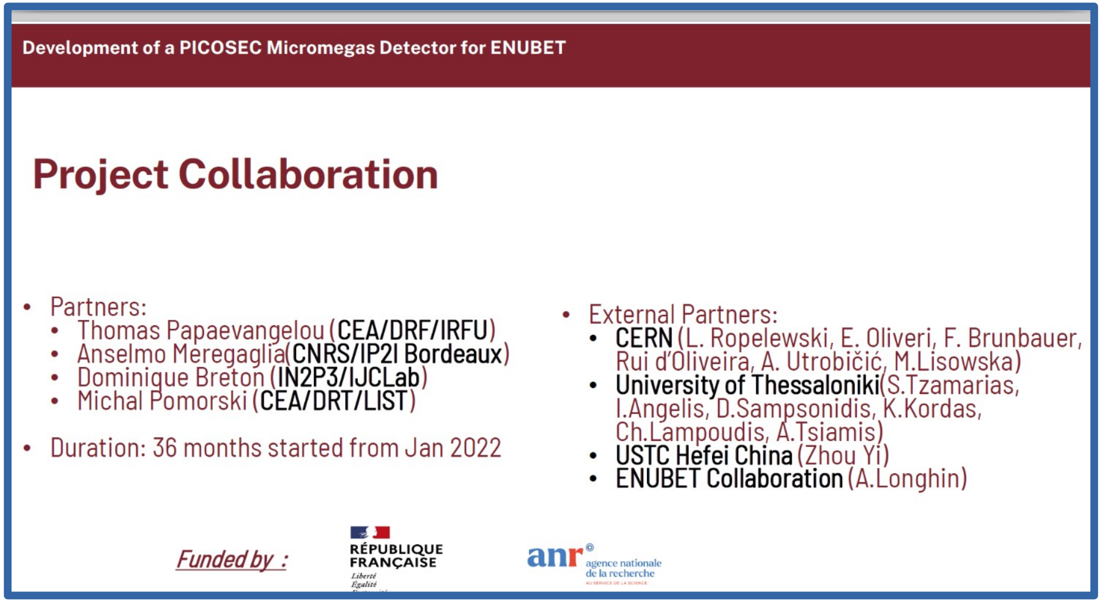
ENUBET @ CERN-PS –T9
16-29 Aug 2023

PIMENT and ESSnuSB+

New funding: **PIMENT (2022-25)**

French ANR

PICOSEC **M**icrom**E**gas Detector for **E**NUBE**T**



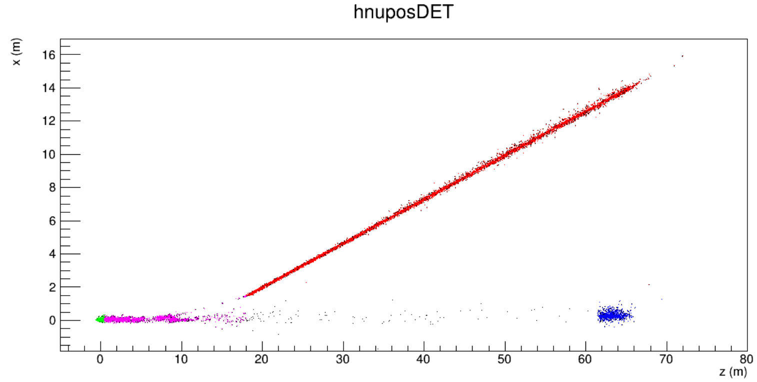
ESSnuSB+ WP6: could the idea of ENUBET be exploited also at the ESS proton driver using pions monitoring (E_{prot} = 2 GeV) ? See dedicated talk at the dedicated workshop here:

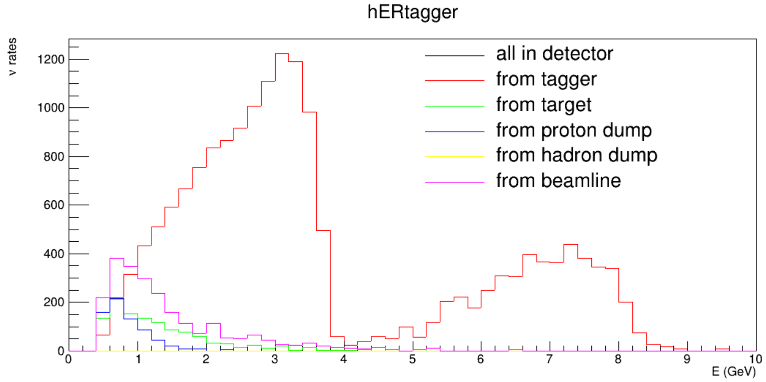
https://indico.cern.ch/event/1216905/contributions/5533277/attachments/2700208/4686626/LEMNB_WP6_NuFact2023_v2.pdf

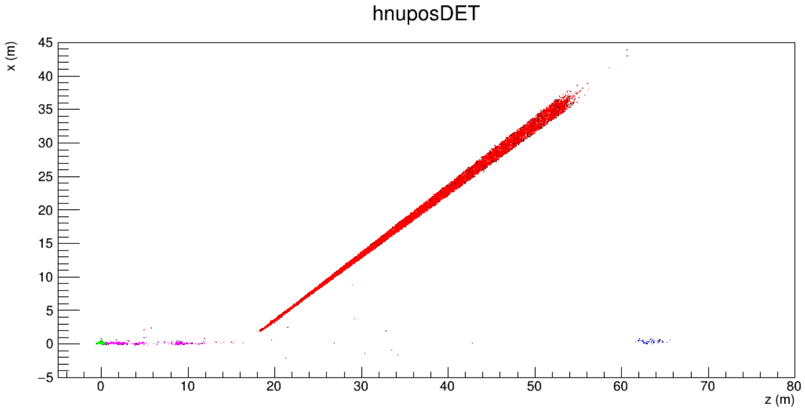
ν_μ^{CC} spectra at detector

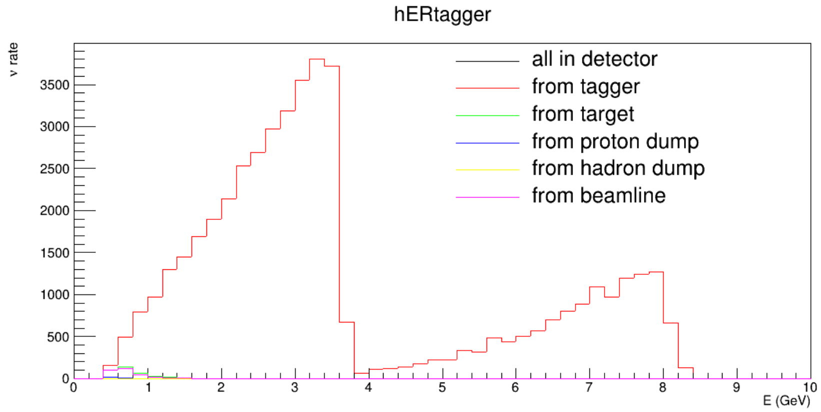
With a SC second dipole

tlr6v6





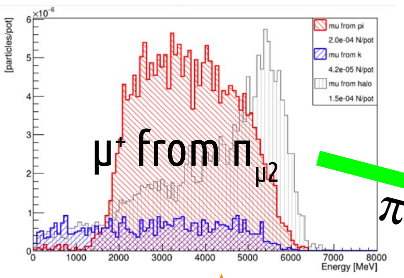


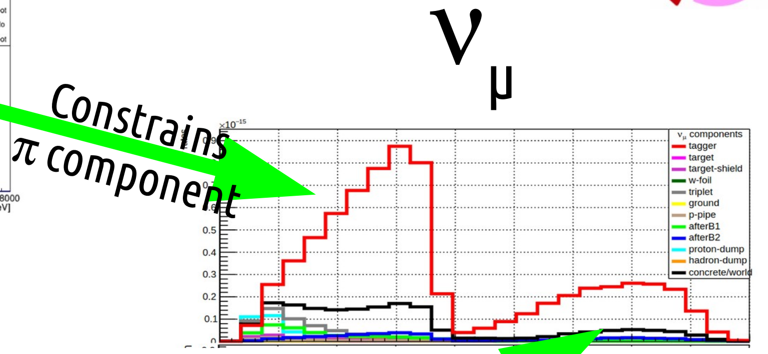


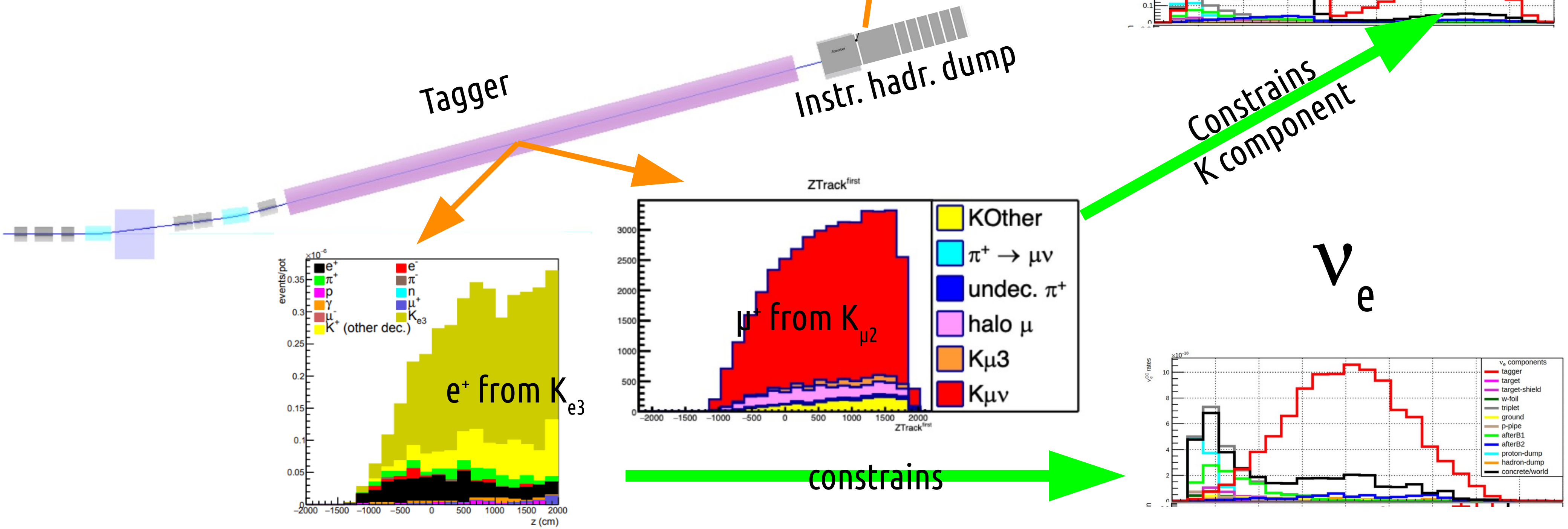
Oveview on lepton monitoring at 400 GeV

Tagger: leptons from K (ν_e and high-E ν_μ)

Hadron dump instr: μ from π (low-E ν_μ)



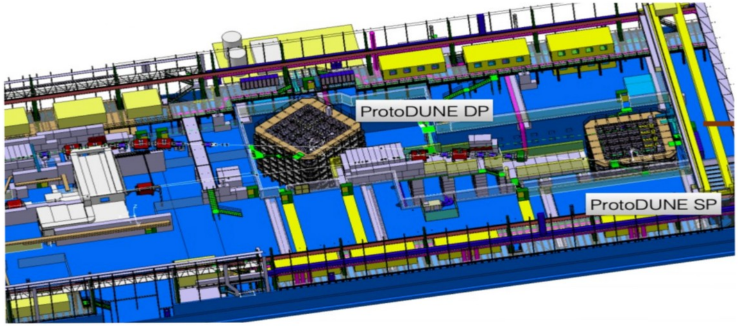




Implementation scenarios

- So far a very successful R&D!
- Next → deliver of a Conceptual Design Report
- Proposing a short baseline neutrino experiment @ CERN exploiting the SPS and the protoDUNE detectors
- Run during DUNE and Hyper-K data taking

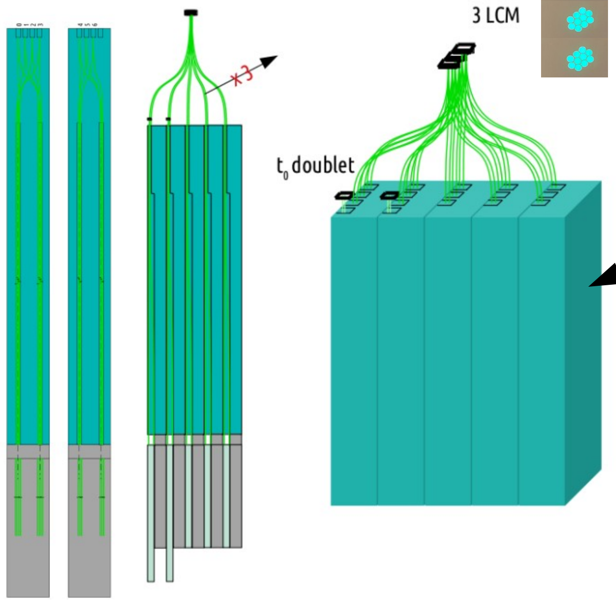
- **"cheap" scenario**: dedicated beamline extracted from the North Area to the PD
  - Maximum use of existing facilities
  - Slow extraction easily implemented
  - Strong interference with other experiments
  - Potential radiation issues
- **"clean" scenario**: dedicated extraction line near the N.A. pointing to PD
  - less interference with experiments and existing facilities
  - radiation issues somewhat easier
  - Higher cost

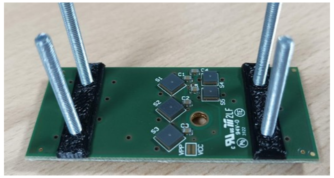


→ Physics Beyond Colliders

The demonstrator

WLS routing





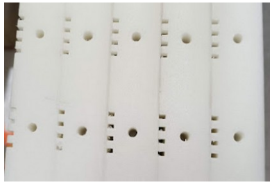
Demonstrate detector performance (PID, homogenity, eff.), scalability, cost effectivess…

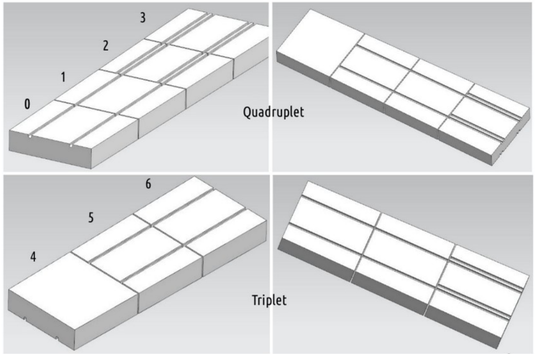
90°, partially instrumented

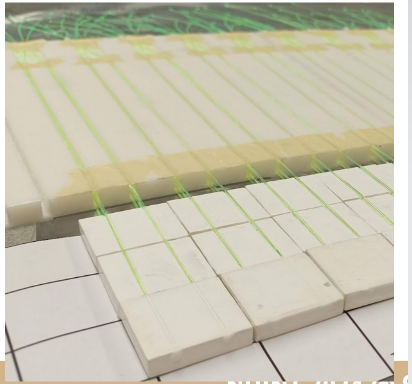
BPE 5%

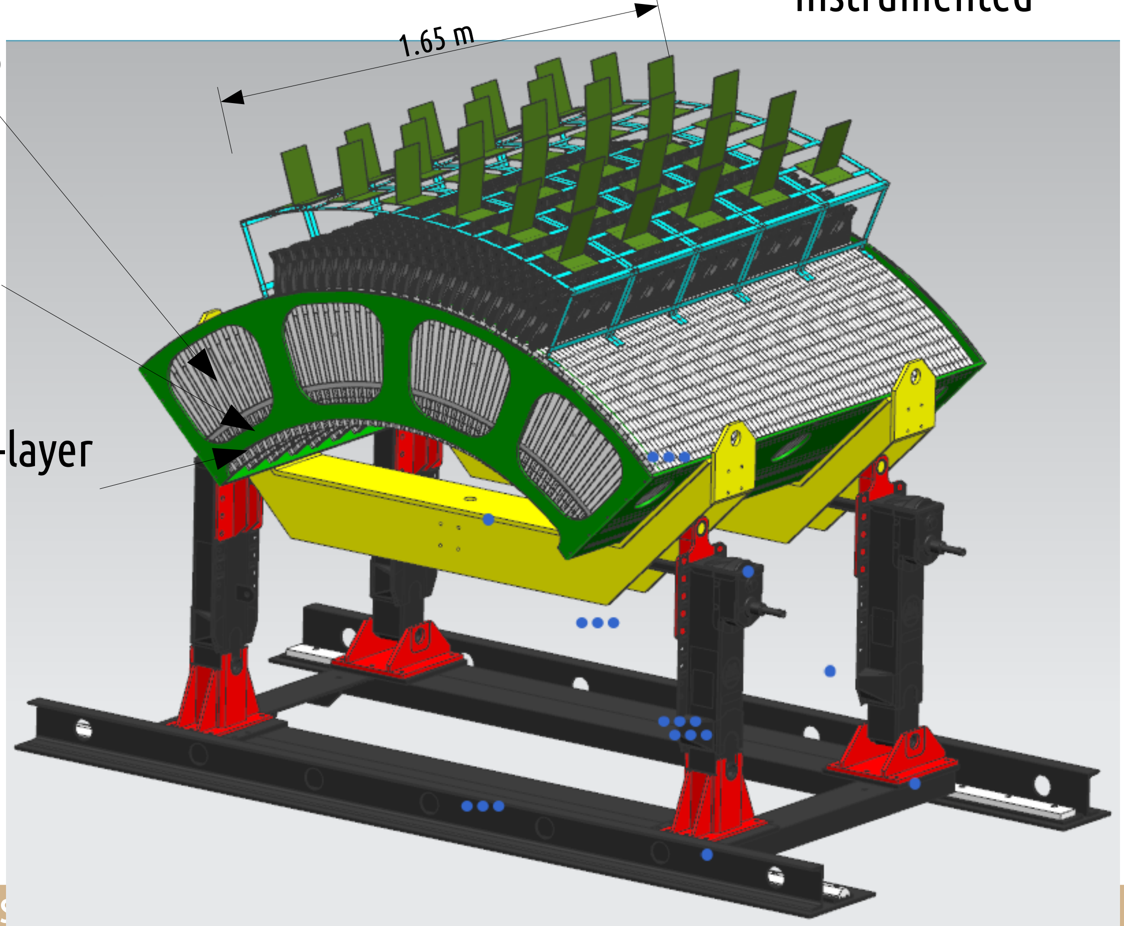
Sampling iron/scint calo

t_0-layer



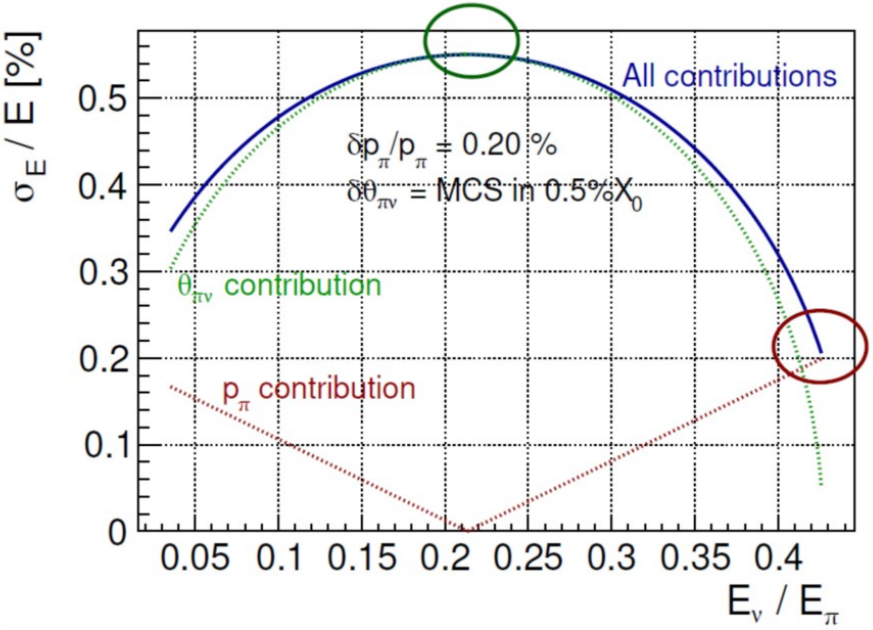






NUTAG

M. Perrin



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

ν_e^{CC} spectra at detector

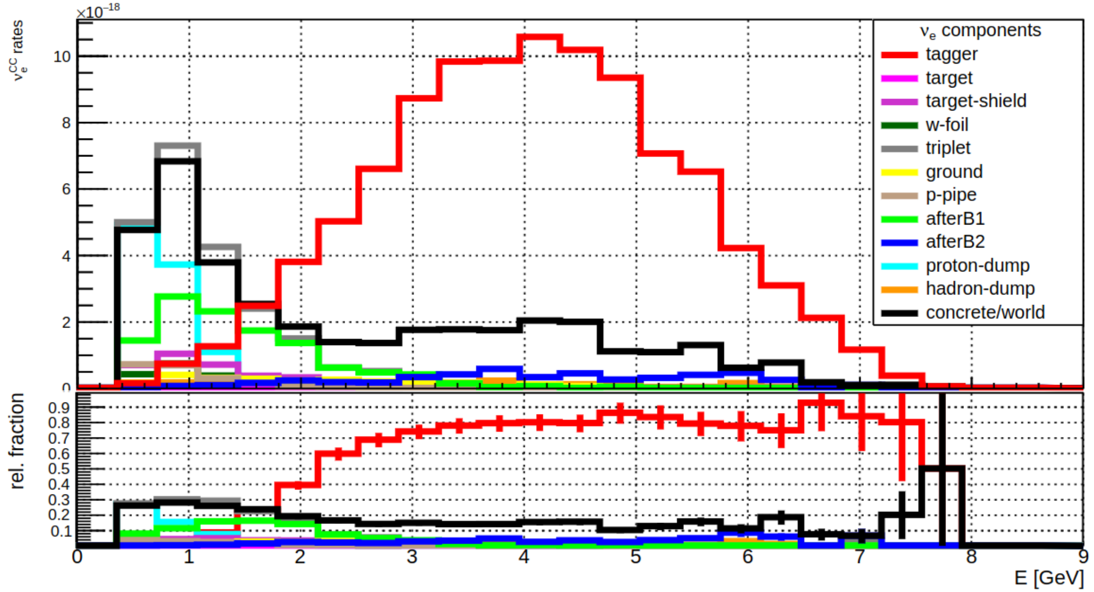
500t @ 50 m after the hadron dump
@ 400 GeV → **10000 ν_e^{CC}** with 9e19 POT (2-3 y)

- ν_e from $K^{+/-}$ in the instrumented region
- ν_e from $K^{0+/-}$ in the proton/hadron dump

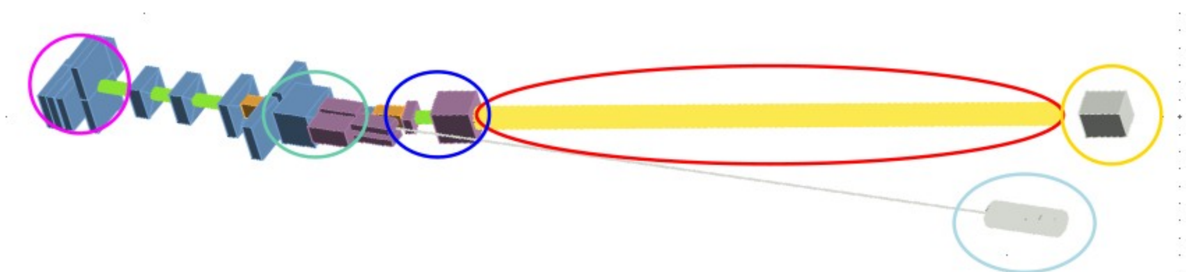
→ reduce by tuning the dump geometry/location

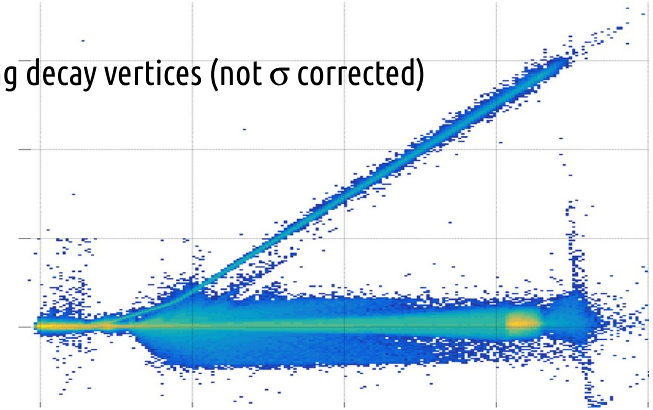
- ν_e from $K^{+/-}$ in front of the tagger

(after 1st bend/2nd bend) contamination → accounted for with simulation (~geometrical).



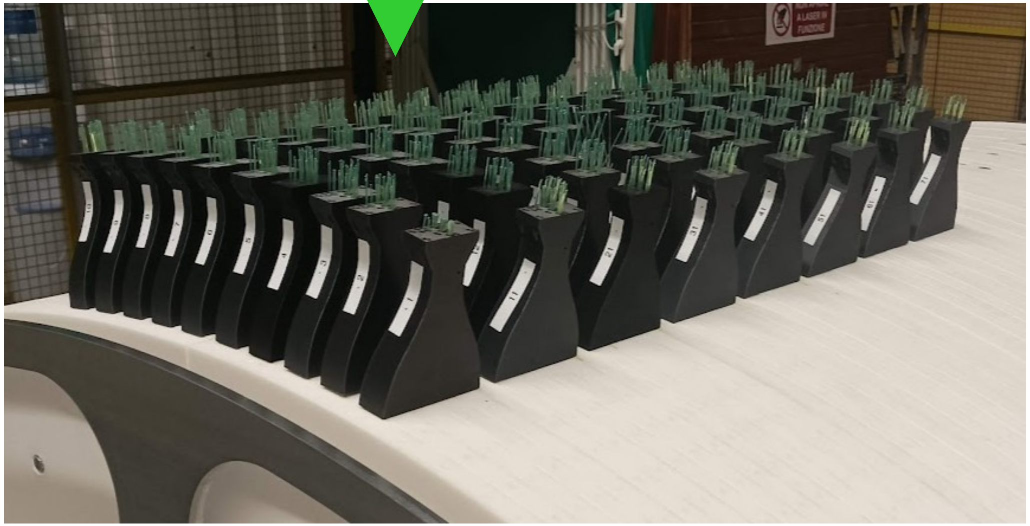
ν producing decay vertices (not σ corrected)

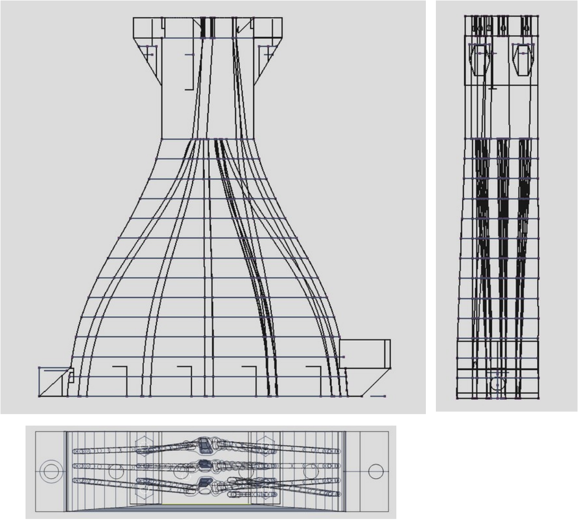




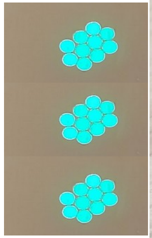
Fiber bundling with “concentrators”

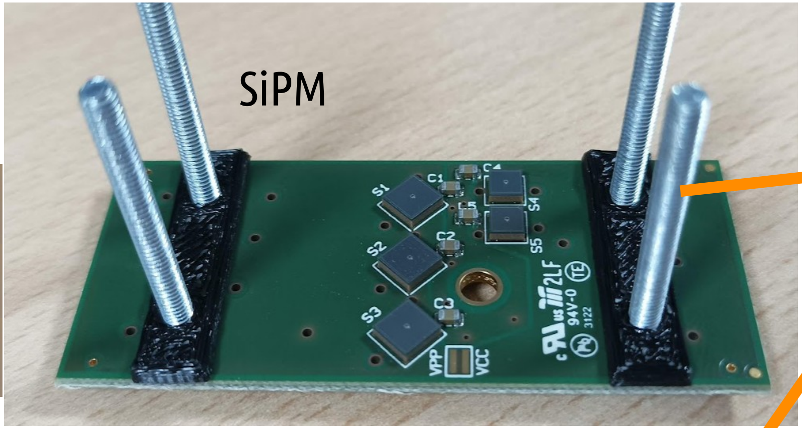
bundling of the WLS fibers with 3D printed “fiber concentrators”+ in situ polishing

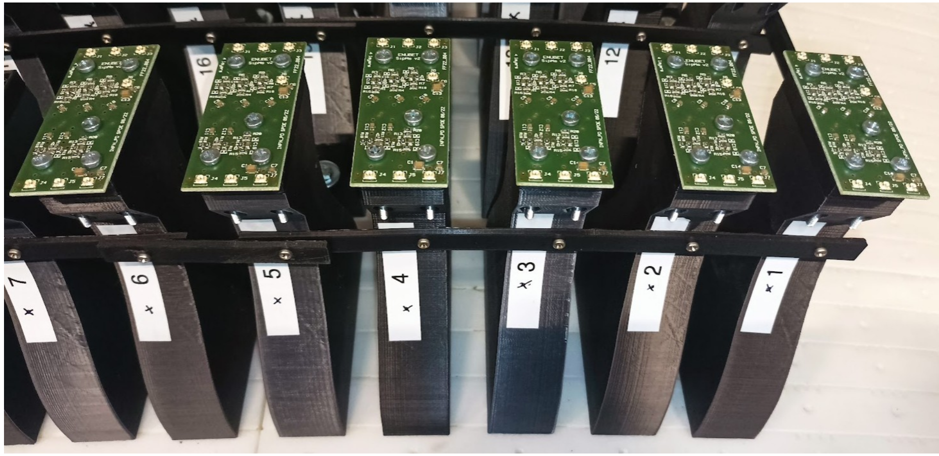


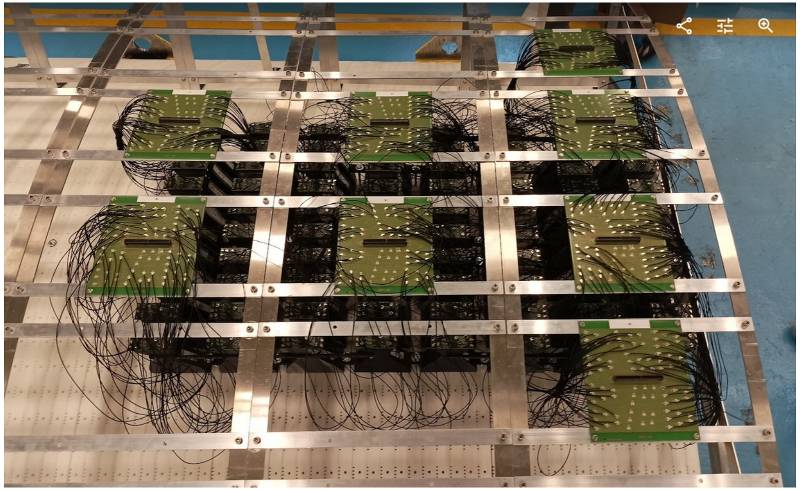


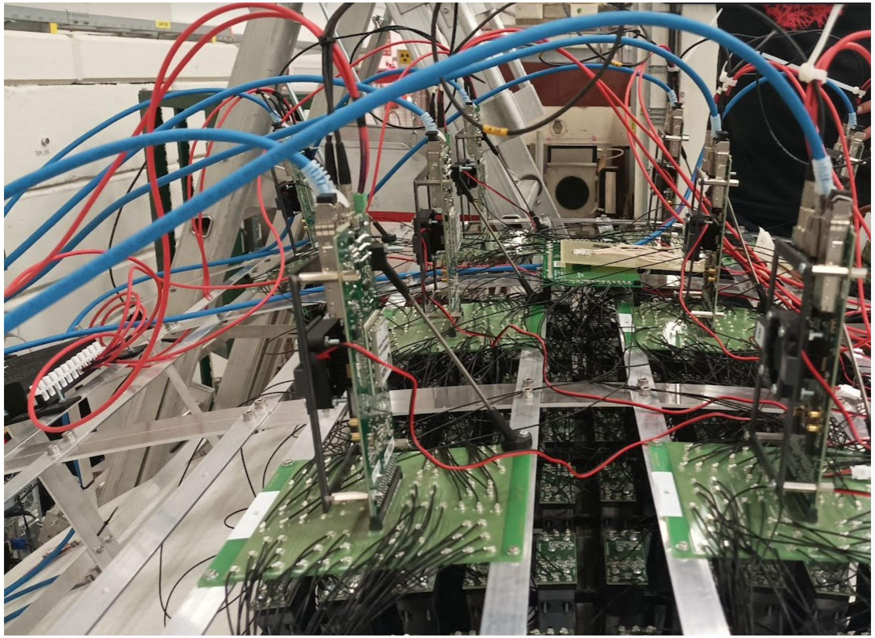
Readout scheme





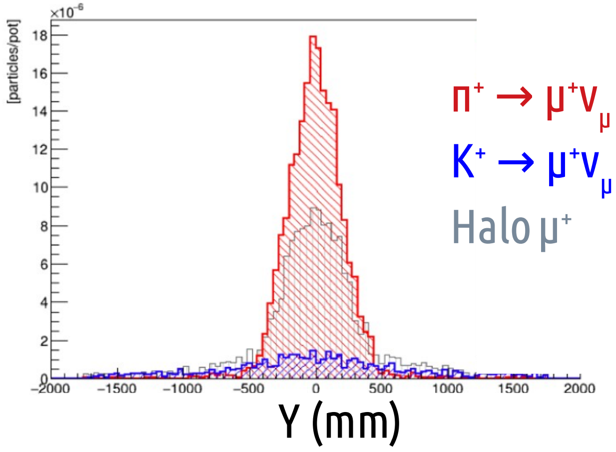


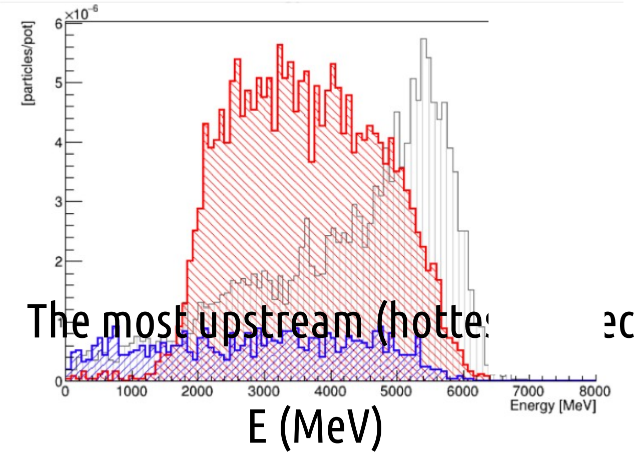


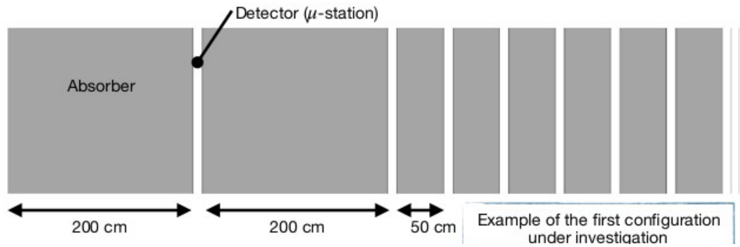


Forward region muons reconstruction

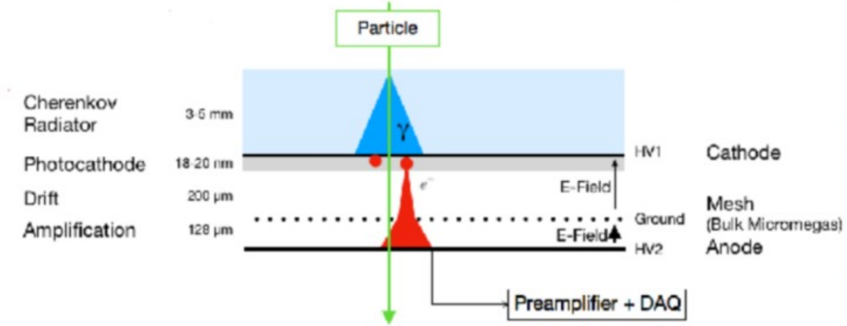
Range-meter after the hadron dump. Extends the tagger acceptance in the forward region to constrain $\pi_{\mu 2}$ decays contributing to the low-E ν_μ.

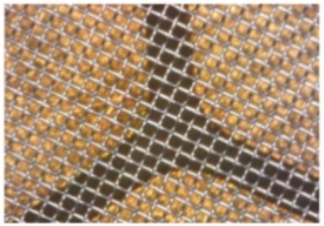






The most upstream (hottes… …ector needs to cope with a muon rate of ~ 2 MH…





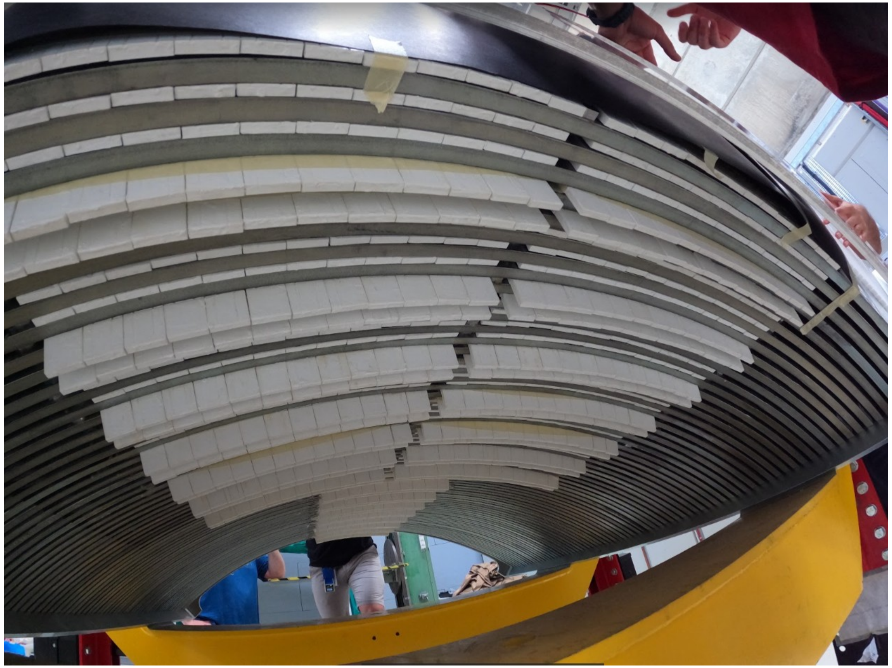
Micromegas detectors employing Cherenkov radiators + thin drift gap ?
Bonus: cutting-edge timing (O(10) ps).

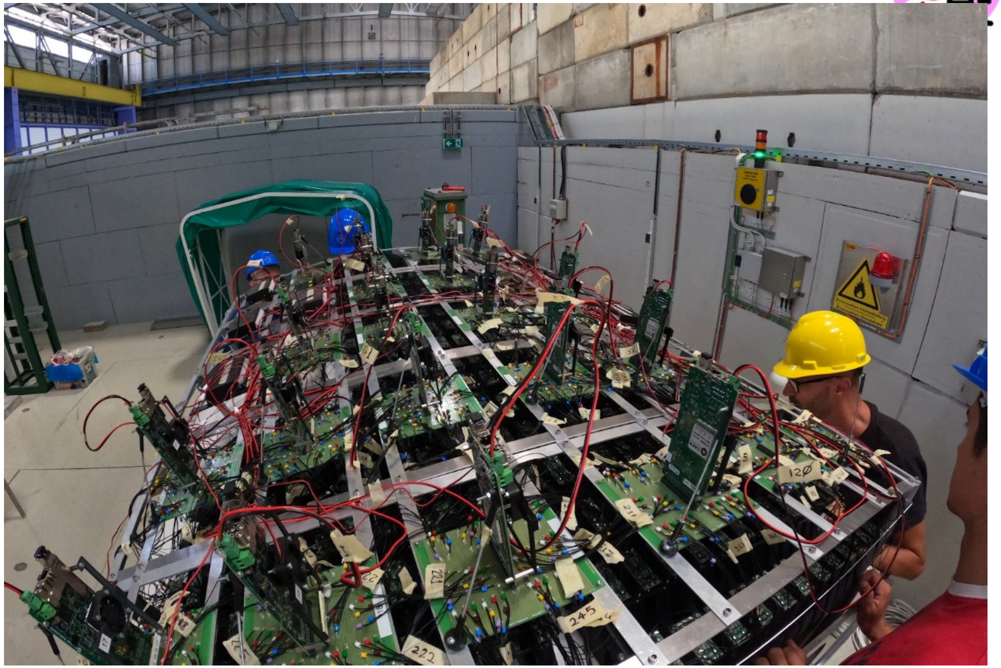
→ PIMENT project ! →

ENUBET: demonstrator

Assembly timelapse

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

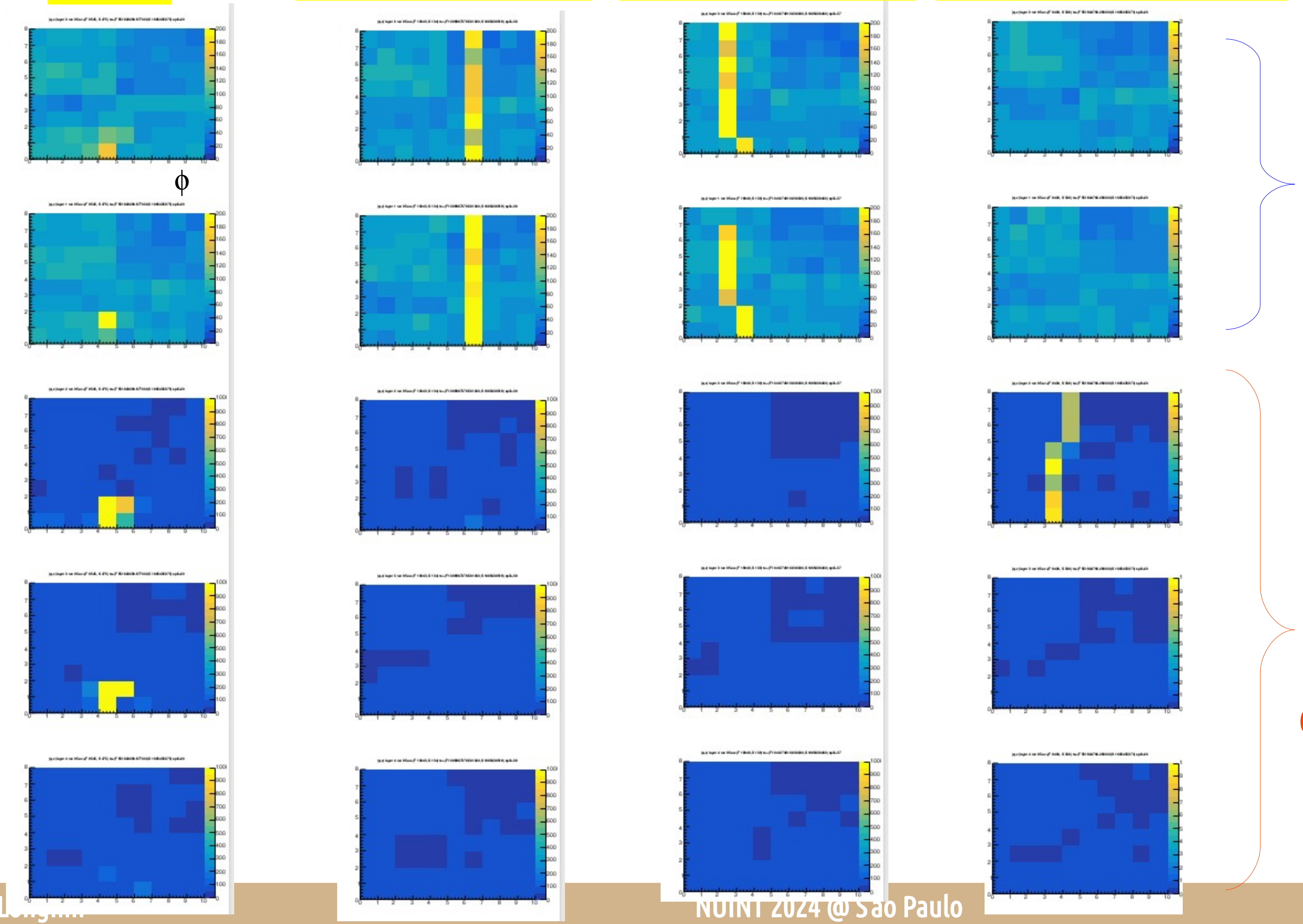




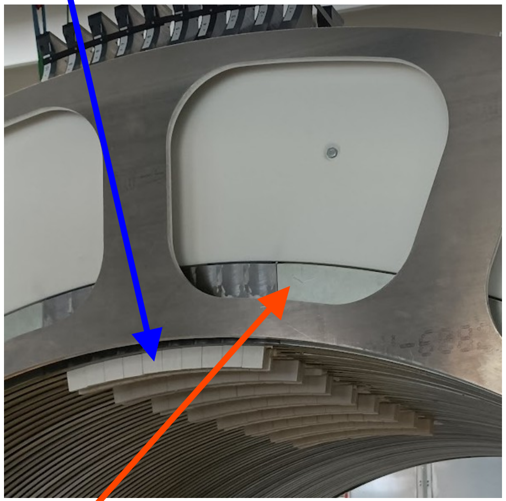
Event displays

Oct 2022 CERN-PS-T9

e-like	mip-like in t_0-layer	mip-like in t_0-layer	mip-like in 1 layer of calo



Tracker layers ("t_0")



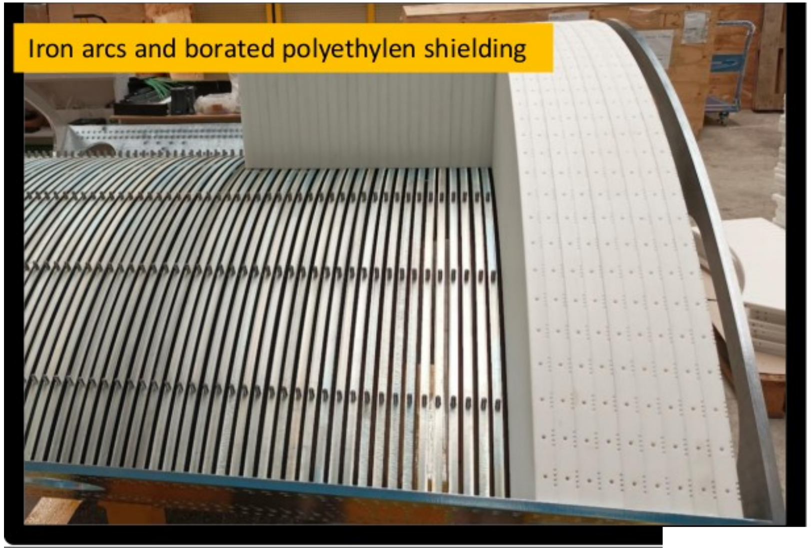
calorimeter layers

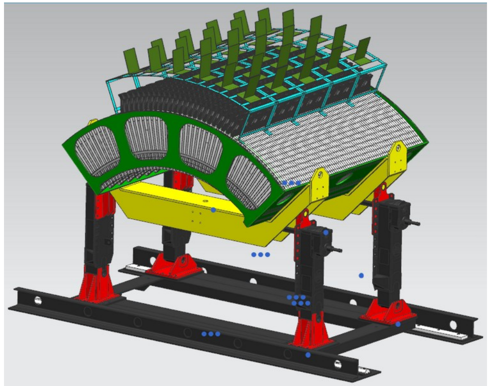
NB: here channels not equalized with mips.

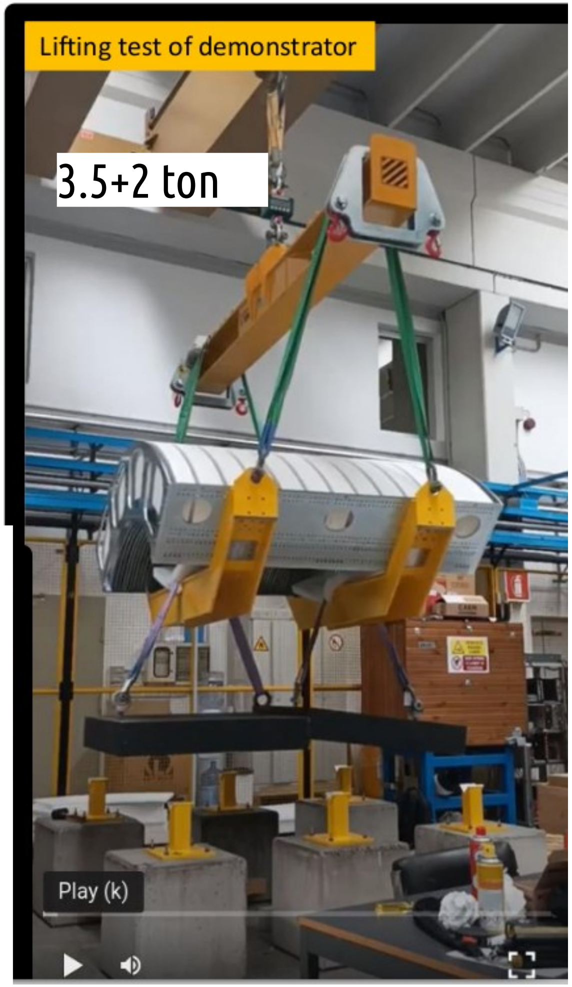
The ENUBET demonstrator in numbers

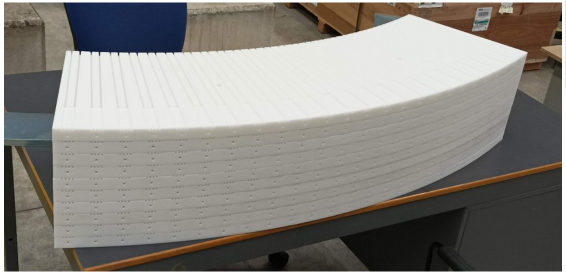
- Scintillator tiles: **1360**
- WLS: ~ **1.5 km**
- Channels (SiPM): **400**
  - Hamamatsu **50 um** cell
    - **240** SiPM **4x4** mm^2 (calo)
    - **160** SiPM **3x3** mm^2 (t_0)
- Fiber concentrators, FE boards: **80**
- Interface boards (hirose conn.): **8**
- Readout 64 ch boards (CAEN A5202):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

Demonstrator construction at LNL-INFN labs

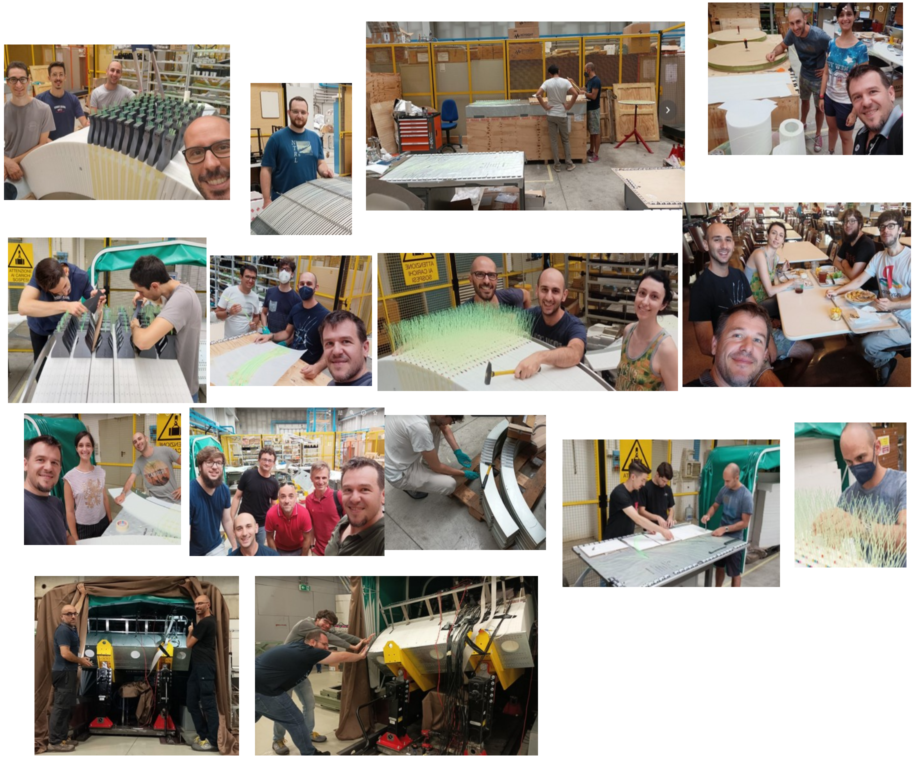








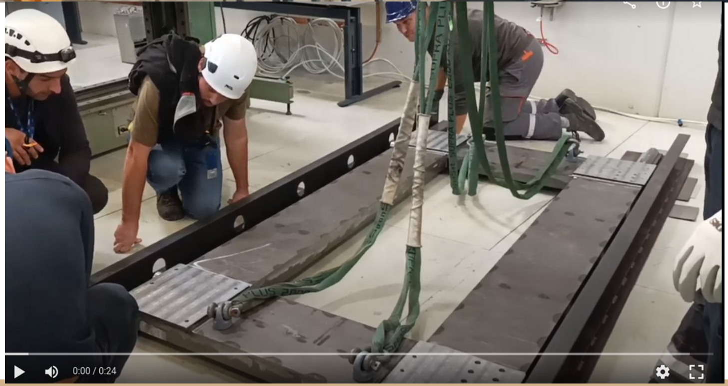
Group pictures



ENUBET takes off !!!

3 Oct 2022 @ building 157,
CERN Meyrin PS East Hall
T9 area

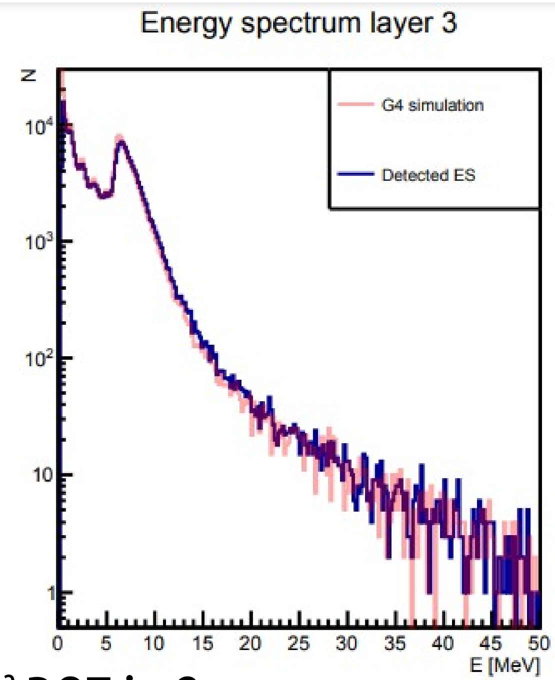
Movable platform "landing site" @ T9 test beam area.



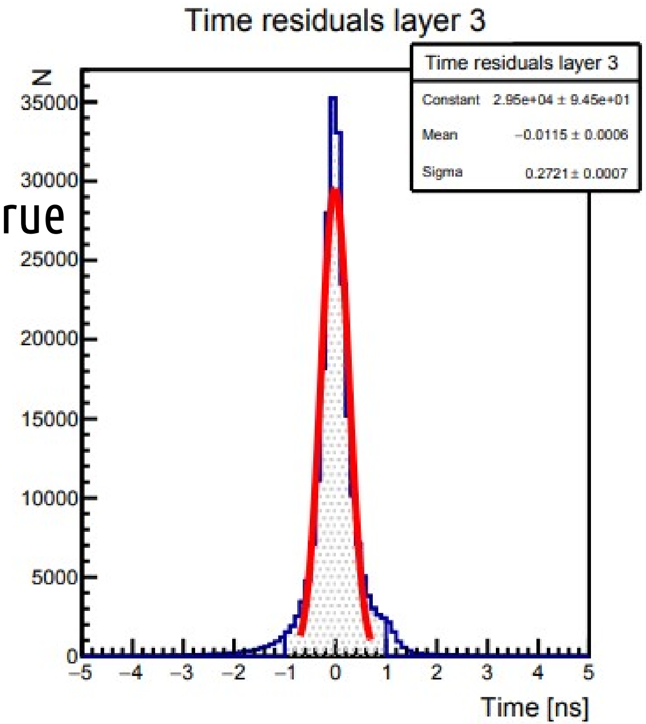
Event pile-up analysis

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.



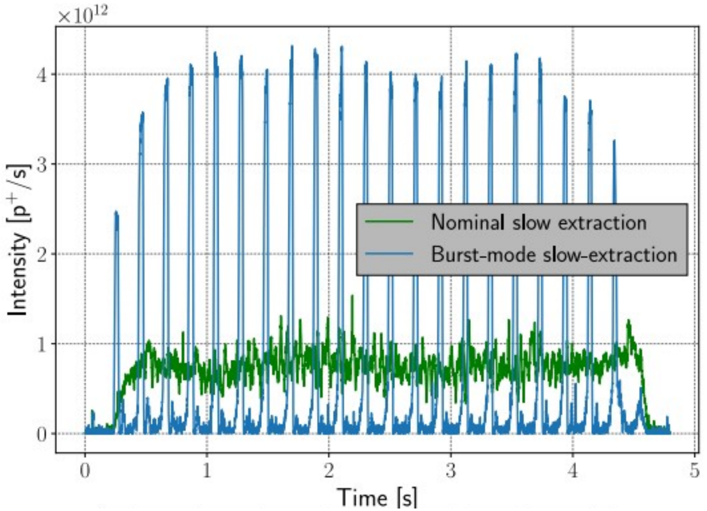
With 4.5 x 10^{13} POT in 2s

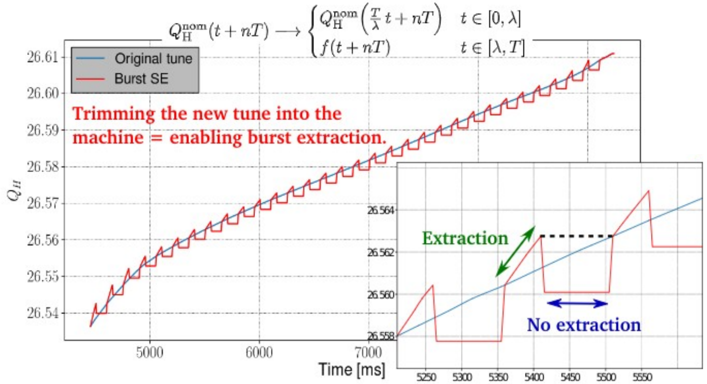
- 1.1 MHz rate in the hottest channels
- Peak finding efficiency = 97.4 %

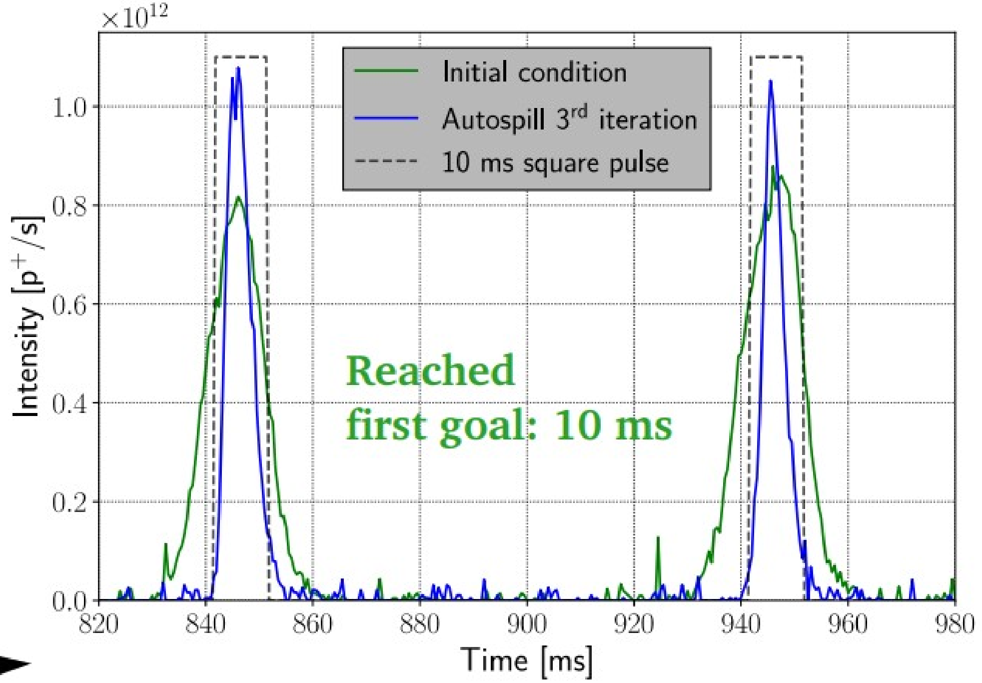
Proton extraction R&D for horn focusing

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





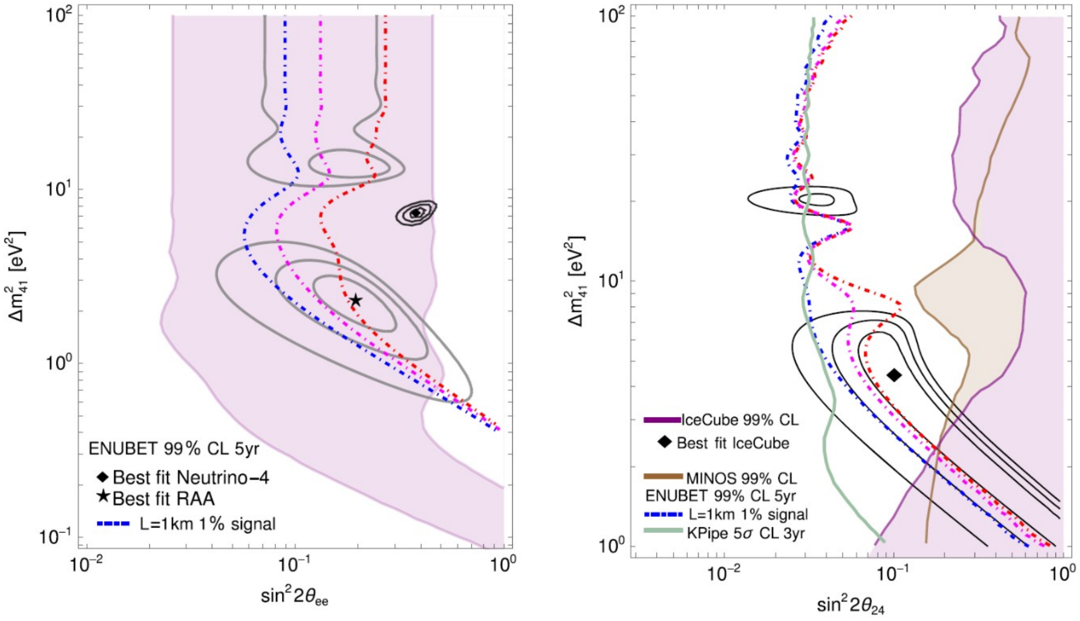


PhD thesis of M. Pari (UniPD + CERN doctoral).
Defended 23/2/21.

BSM

Sterile neutrinos: some results already available

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



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

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]

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!