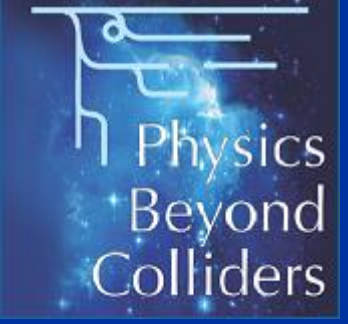


ENUBET & NuTag: Studies for tagged neutrino beams in the Conventional Beams Working Group

N. Charitonidis, A. Baratto-Roldan & E. Parozzi* (CERN, BE-EA), on behalf of the CBWG

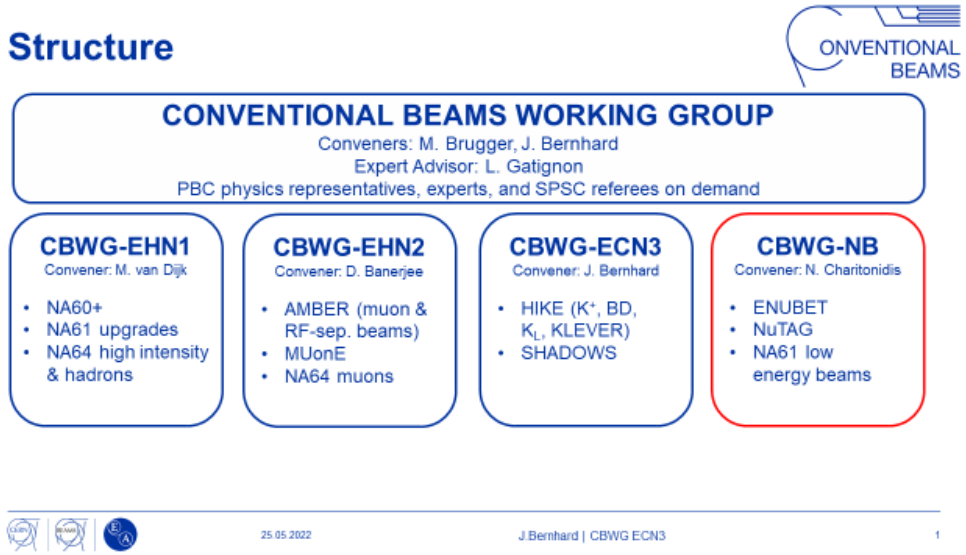
* Also with University of Milano – Bicocca, Italy

08.11.2022

ONVENTIONAL
BEAMS

Conventional Beams – Neutrino Beams subgroup

- **The conventional beams working group deals with the neutrino-related projects of the PBC-CBWG**
  - Currently : ENUBET, NuTag and NA61-VLE → The latest evolved as an SPSC addendum and an ECR is under preparation, along with funding requests by NA61.



- **Members of the subgroup :**
  - **A. Baratto – Roldan, N. Charitonidis , M. Gazdzicki, A. Longhin, Y. Nagai , E. Parozzi, K. Sakashita, M. Perrin-Terrin, F. Terranova**

NB subgroup internal organisation

ONVENTIONAL BEAMS

- **Monthly meetings where results are shown and iterated between the various projects**
- **Reports from various studies**
  - Share knowledge and challenges
  - Technical assistance in our areas of expertise
  - Possibly share software (or even hardware!) tools that can be of common interest
- **Evaluating & listing the resources requests (also in collaboration with the other CBWG subgroups) that could become in the future available**
- **Indico space for ad-hoc meetings and discussions**
  - Special invitees contribute also in the discussions
- **Feedback from the subgroup will be included to the PBC-CBWG next report**

Conventional Beams – Neutrino Beams subgroup

ONVENTIONAL BEAMS

https://indico.cern.ch/category/14358/

Neutrino Beams Meetings

Neutrino Beams related projects.
Chairperson: N. Charitonidis
Scientific Secretary: E. Parozzi

- NuTAG Meetings
- General Meetings
- NA61-LowE Technical Meetings

General Meetings

Enter your search term

October 2022

12 Oct PBC - Conventional Beams - Neutrino Beams Subgroup Exceptional Meeting

September 2022

07 Sept PBC - Conventional Beams - Neutrino Beams Subgroup Discussion #11

July 2022

20 Jul PBC - Conventional Beams - Neutrino Beams Subgroup Discussion #10

June 2022

29 Jun PBC - Conventional Beams - Neutrino Beams Subgroup Discussion #9

May 2022

24 May PBC - Conventional Beams - Neutrino Beams Subgroup Discussion #8

03 May PBC - Conventional Beams - Neutrino Beams Subgroup Discussion #7

April 2022

08 Apr PBC - Conventional Beams- Neutrino Beams Subgroup Discussion #6

March 2022

ENUBET – Introduction

ONVENTIONAL BEAMS

- **A large collaboration, 13 institutions**

The rationale of ENUBET

Courtesy: F. Terranova

The knowledge of neutrino cross section is stuck at 10-30 % level and the needs of the neutrino community are at 1% level because:

- Leading systematics for long baseline experiments → Neutrino Oscillation Physics
- Limited possibility to validate nuclear electroweak effects ("nucleus and nuclear correction") → Electroweak physics
- Neutrino generators based on different approach still provide results with >50% discrepancies → Nuclear Physics

From the **European Strategy for Particle Physics Deliberation document**:

To extract the most physics fromDUNE and Hyper-Kamiokande, a complementary programme of experimentation to determine neutrino cross-sections and fluxes is required. Several experiments aimed at determining neutrino fluxes exist worldwide. The possible implementation and impact of a facility to measure neutrino cross-sections at the percent level should continue to be studied.

From the Physics Briefbook for the **European Strategy for Particle Physics (arXiv:1910.11775)**

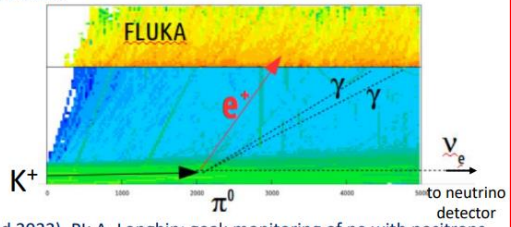
Both nSTORM and ENUBET are to a large extent site-independent concepts, studies and R&D; however both consider a possible implementation at CERN. For nSTORM, under the auspices of the PBC program, an initial study of implementation at CERN was carried out, and no showstoppers have been identified. For ENUBET the option of using SPS as the proton driver has been considered in greater detail with a possible site in the North Area and the ProtoDUNEs as neutrino detectors.
A dedicated study should be set-up to evaluate the possible implementation, performance and impact of a percent-level electron and muon neutrino cross-section measurement facility (based on e.g. ENUBET or nSTORM) with conclusion in a few years time.

What is ENUBET?

Courtesy: F. Terranova

ENUBET is the project for the realization of the first monitored neutrino beam.

"Monitored neutrino beams are beams where diagnostic can directly measure the flux of neutrinos because the experimenters monitor the production of the lepton associated with the neutrino at the single-particle level. "
(Wikipedia)



- ENUBET: ERC Consolidator Grant, June 2016 – May 2021 (COVID: extended to end 2022). PI: A. Longhin; goal: monitoring of ne with positrons
- Since April 2019: CERN Neutrino Platform Experiment – NP06/ENUBET : goal full monitoring of ne and nm
- Collaboration: 60 physicists & 13 institutions; Spokespersons: A. Longhin, F. Terranova; Technical Coordinator: V. Mascagna;

Visit our webpage for further info and material!
https://www.pd.infn.it/eng/enubet/

3

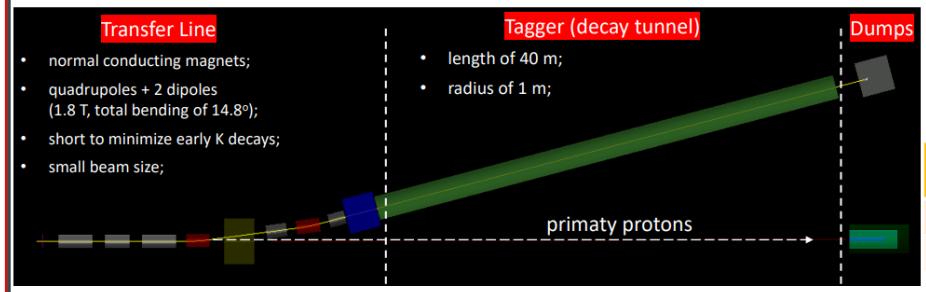
- **ENUBETs idea : Building a monitored neutrino beam at CERN or elsewhere. Main channel of interest the K_{e3} decay ($K^+ \rightarrow \pi^0 e^+ \nu_e$) but also other channels (e.g K_{mu3}, $K^+ \rightarrow \mu^+ \pi_0 \nu_\mu$)**
- **Goal: A ~10^{10} K^+ beam/spill, slowly extracted, to decay inside an instrumented tunnel**

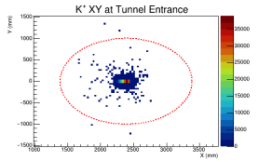
ENUBET – Baseline design

ONVENTIONAL BEAMS

- **Outside the PBC-CBWG-NB, ENUBET has developed a "baseline" beam-line & instrumentation, including test-beams @ PS.**

The ENUBET beamline: (details in A. Branca ICHEP2022)





Rates @ Tunnel entrance for 400 GeV POT	
π^+ $[10^{-3}]$/POT	K^+ $[10^{-3}]$/POT
4.13	0.34

~1.5X w.r.t. previous results

Large bending angle of 14.8°:

- better collimated beam + reduced muons background + reduced ν_e from early decays;

Transfer Line:

- optics optimization w/ **TRANSPORT** (5% momentum bite centered @ 8.5 GeV) **G4Beamline** for particle transport and interactions;
- **FLUKA** for irradiation studies, **absorbers and rock** volumes included in simulation (not shown above);
- **optimized graphite target** 70 cm long & 3 cm radius (dedicated studies, scan geometry and different materials);
- **tungsten foil downstream target** to suppress positron background;
- tungsten alloy **absorber @ tagger entrance** to suppress backgrounds;

Dumps:

- **Proton dump**: three cylindrical layers (graphite core -> aluminum layer -> iron layer);
- **Hadron dump**: same structure of the proton dump -> allows to reduce backscattering flux in tunnel;

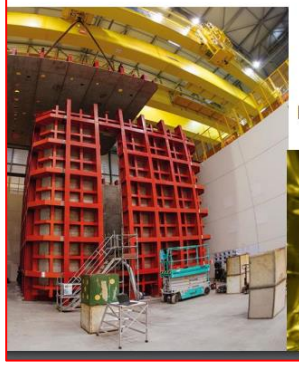
Full facility implemented in GEANT4:
- Controll over all paramaters;
- Access to the paricles histories;

assessment of the nu flux systematics

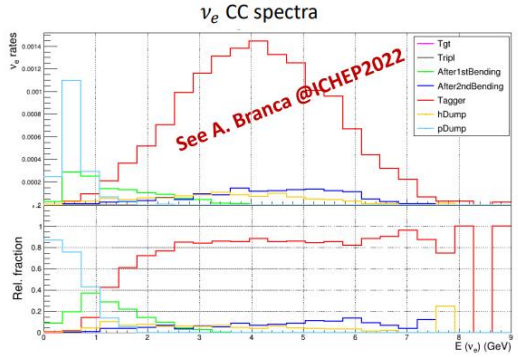
7

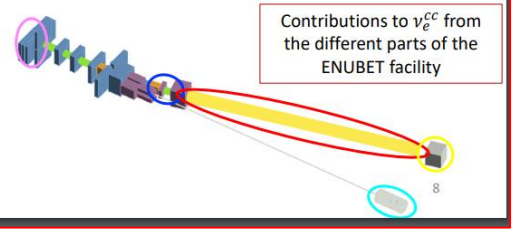
ν_e^{CC} energy distribution @ detector

A total ν_e^{CC} statistics of 10^4 events in ~2 years
- @ SPS with $4.5 \cdot 10^{19}$ POT/year;
- 500 tonne detector @ 50 m from tunnel end;



ProtoDUNE-SP (NP04)





Contributions to ν_e^{cc} from the different parts of the ENUBET facility

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- **Assuming 4.5x10[19] p/year @ 400 GeV/c and using ProtoDUNE-SP as detector (NA extension) ENUBET would aim to collect a <u>total of 1E4 events in 2y</u>**
  - <u>ENUBET will ask to launch a preliminary feasibility study for 2023</u>

ENUBET – Multi-Momentum beam line

ONVENTIONAL BEAMS

- **The “baseline design” of ENUBET focuses on a momentum of 8.5 GeV/c**
- **Within the PBC-CBWC-NB, a new design has been developed :**
  - “Multi-Momentum” beam line (4, 6 & 8.5 GeV/c), opening even more possibilities for different physics
  - With **existing, well tested CERN magnets** (QPL, QWL and MCB type, possibly their laminated versions) and their corresponding geometries and well-characterized fields
  - Double bend achromat in the middle assures first-order zero dispersion optics and reasonable spot-size at the decay tunnel
  - Careful target optimisation performed, including various production angles for background control.
- **Doctoral Thesis of E. Parozzi (Univ. Milano Bicocca) – under preparation**
  - Posters and presentations for this line given in IPAC and other conferences
    - IPAC-2022 along with the rest of PBC projects
    - IPAC-2021 poster & proceedings focused only on the Multi Momentum Beam Line
    - Talk in NuFact-22 for both the baseline & the “multi-momentum” versions

ENUBET – Multi-Momentum beam line performance

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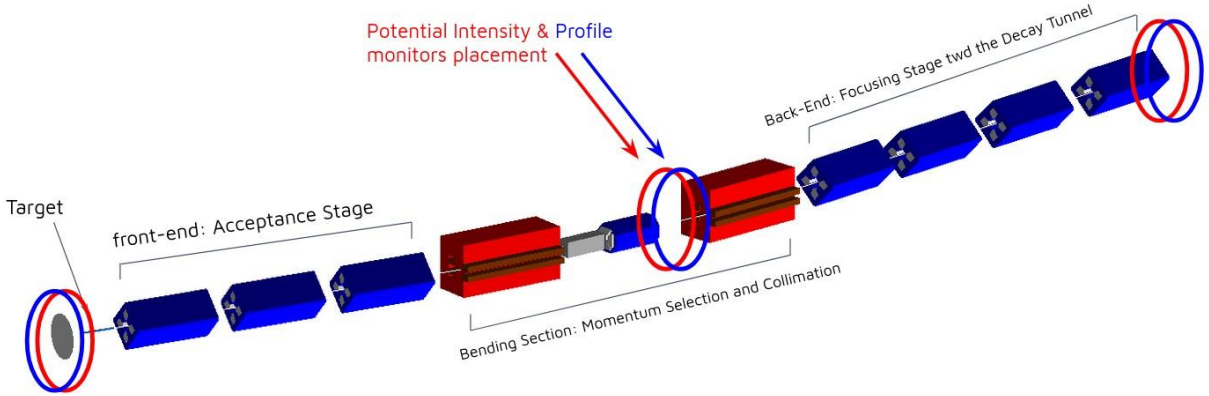
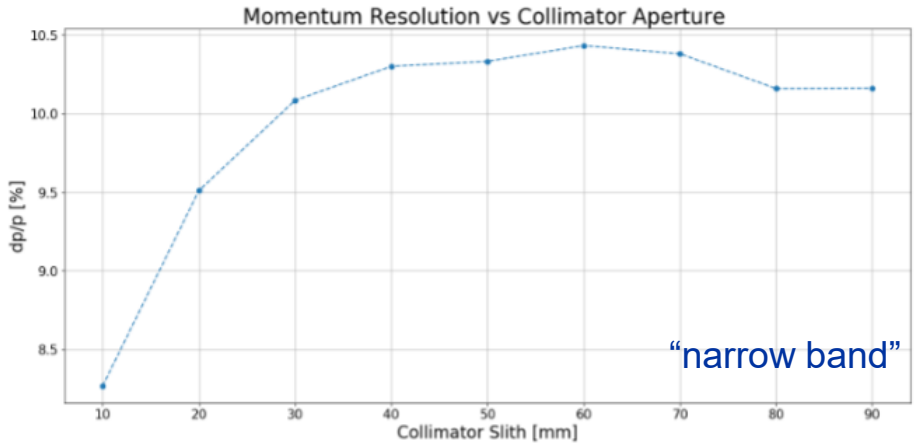
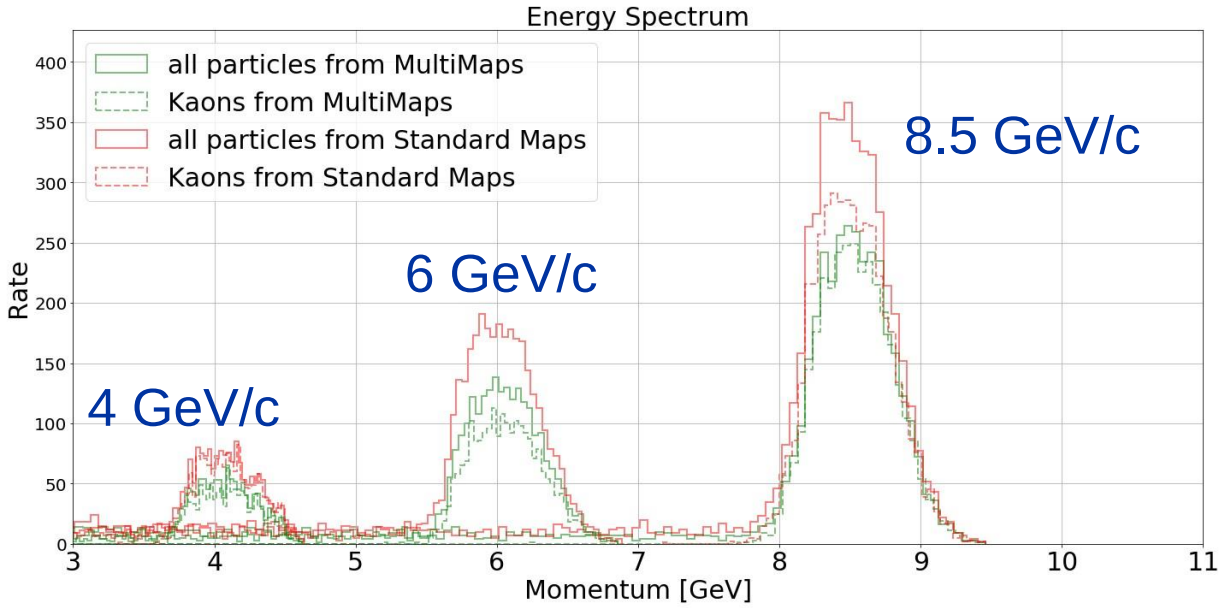
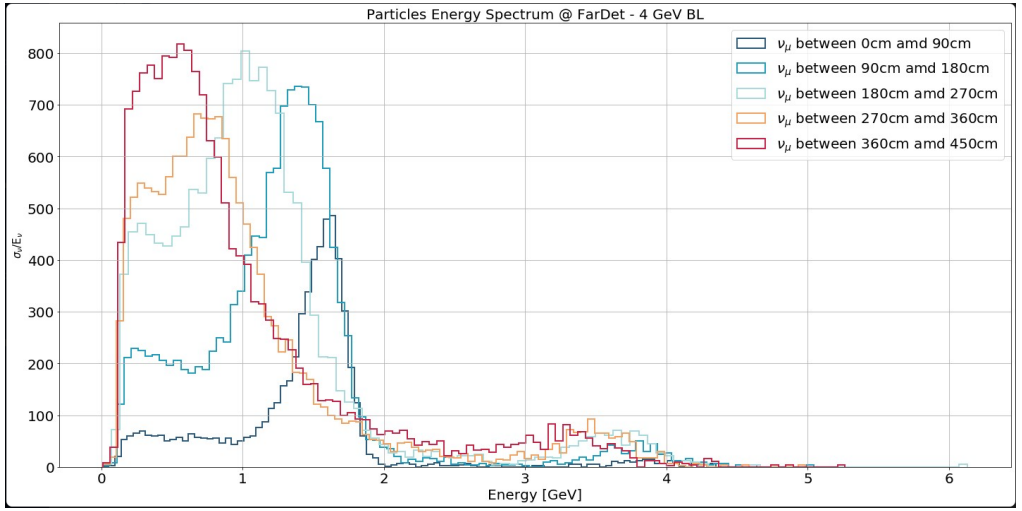
E. Parozzi









ENUBET – Demonstrator

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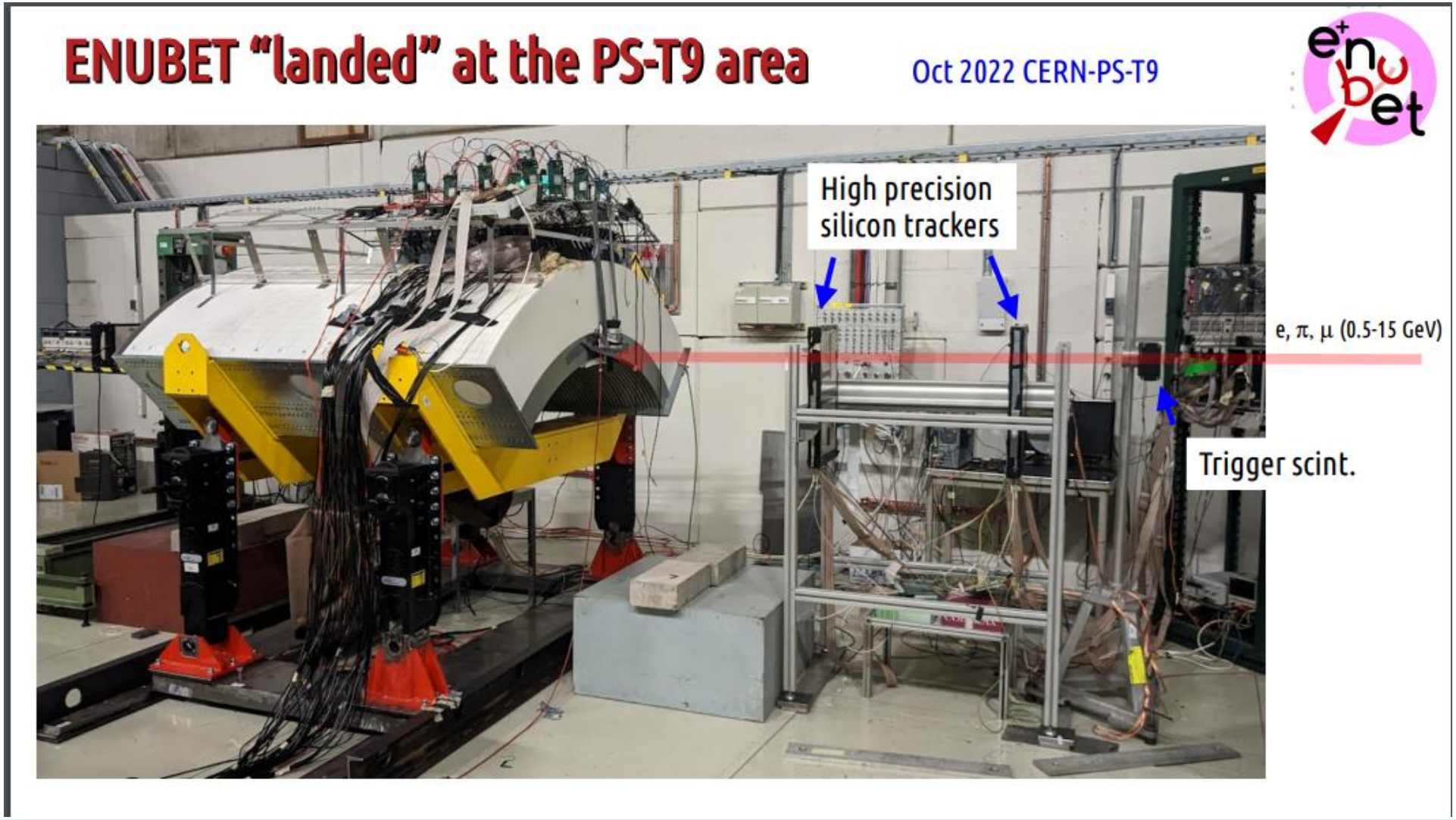


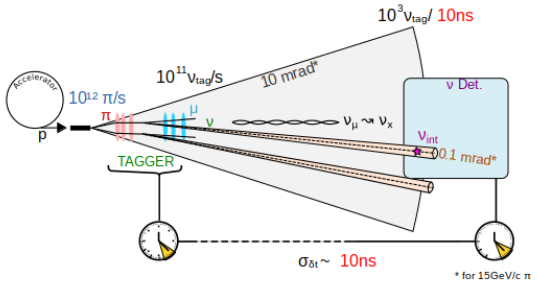
NuTag: A new idea that ‘got alive’ in PBC-CBWG-NB

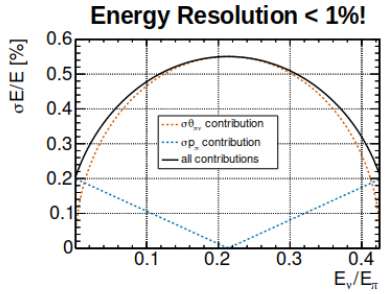
ONVENTIONAL BEAMS

M. Perrin – Terrin – Relevant Publication

Recall of the idea

- Method for **accelerator based neutrino experiments**
- Determine **neutrino property** using **production mechanism: $\pi^+ \rightarrow \mu^+ \nu_\mu$**
  - Install **trackers** in beam line to **kinematiclly reconstruct ν_μ** from π and μ
  - **Associate ν** seen in the detector with the tagged-ν using time and angular coincidence.

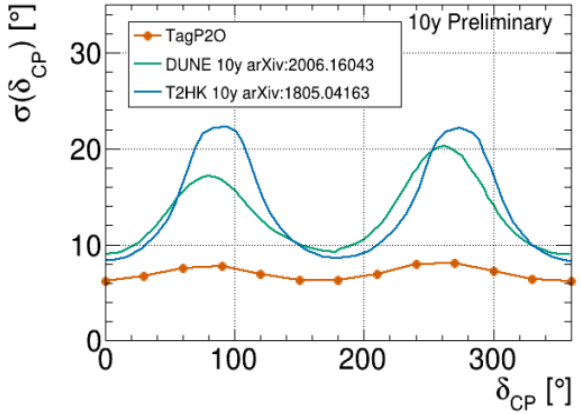




03/10/2022 Mathieu PERRIN-TERRIN (CPPM)

NuTAG and Tag P2O

- Excellent sensitivity to δCP

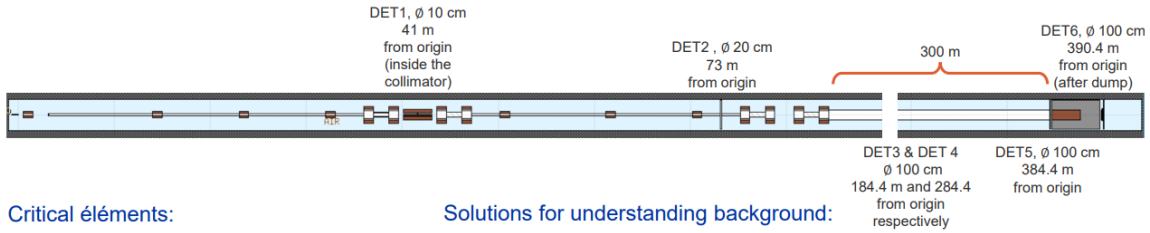


- **Beam line design done within the WG (A. Baratto & E. Parozzi)**
  - Two versions of a possible solution for NuTag in terms of beam line design have been developed in the past year, and preliminary results with pros / cons of each already exist

NuTag beam-line design

FLUKA simulations for background studies

Full simulation

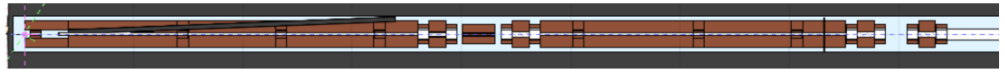


Critical éléments:

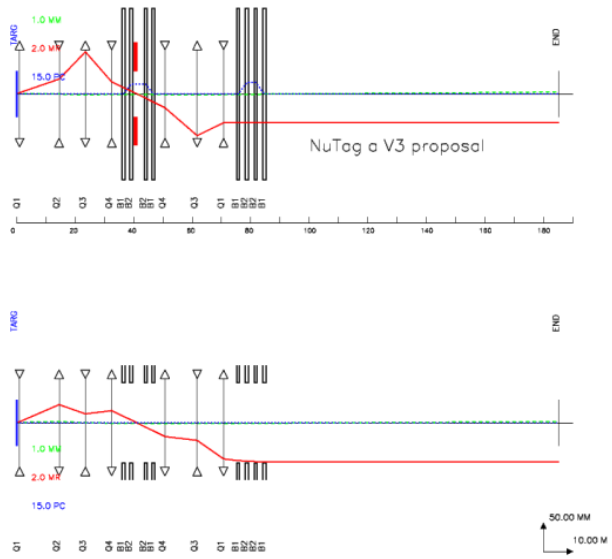
- IRON of the magnets
- IRON of the collimator (TAX)
- Final Dump
- Stray particles from primary beam

Solutions for understanding background:

- Set IRON to BLACKHOLE
- Remove final dump
- Set STEEL of beam pipes to BLACKHOLE
- Absorbe primary beam and SHIELD



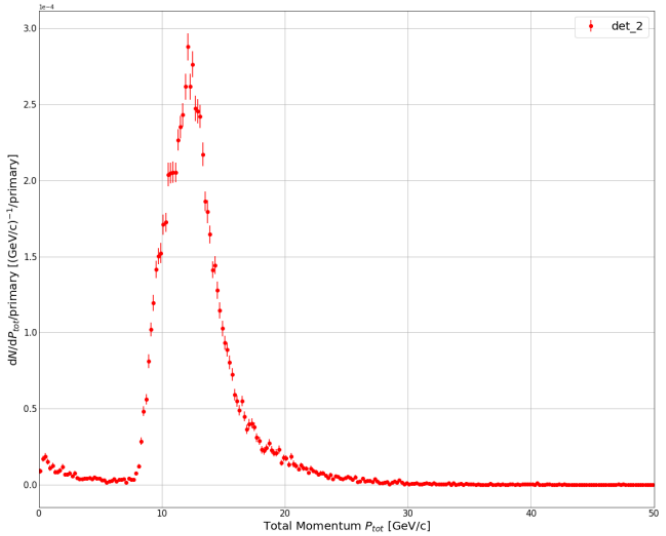
- A first design of **optics** & **layout** is being studied with preliminary results, more studies are necessary to evaluate the performance
- Simultaneous transport of π+ and π-
- An LBL with a far detector in Italy or Greece (apart from a possible SBL) is also being considered with first estimations ongoing.



A. Baratto - Roldan
E. Parozzi

- Two achromat sections for momentum selection (12 GeV/c) and pion tagging
- Parallel beam and “decay tube”

Results: Momentum spread and particle rate



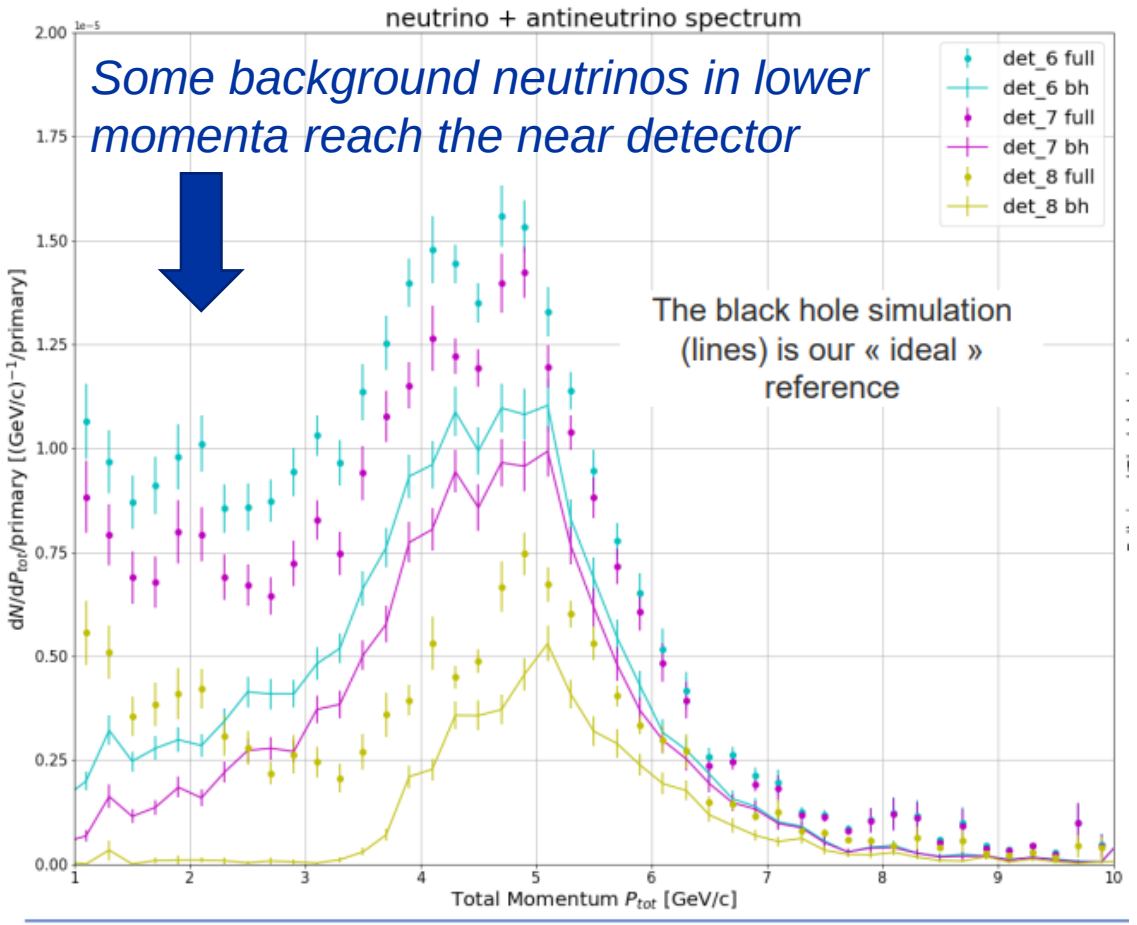
Momentum spread:
- Measured before second achromat (detector 2)
- 21% (δp/p)
- Could be improved by closing the collimator, currently 10 cm Ø

Charged particle rate (measured at second achromat):
- For a spill of 1.E+13 of a duration of 5 s
- On a surface of approximately 5.E+4 mm² (considering a beam size of 40 cm x 12 cm)
- Approximately 7.E+04 particles/s/ mm²

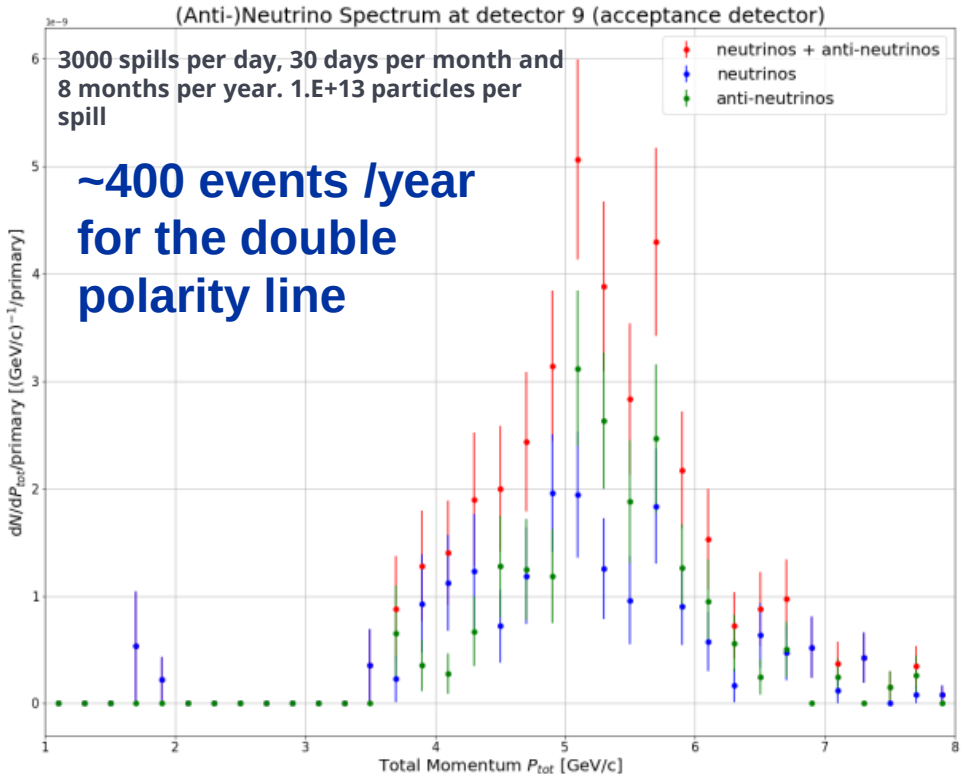
Preliminary results at near & far detectors

ONVENTIONAL BEAMS

A. Baratto - Roldan



"Far" detector acceptance first estimates



"TRITON" has submitted an ERC grant application for the continuation of the studies

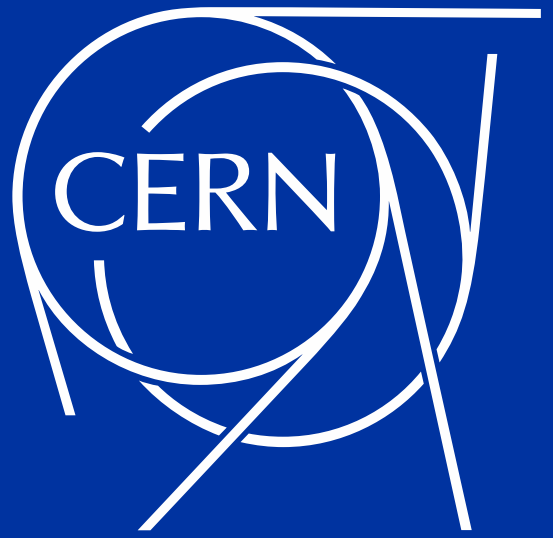
Conclusions

- **Many advancements in ENUBET & NuTag in the last year within the framework of the PBC-CBWG-NB subgroup**

- **ENUBETs Multi-Momentum beam line shows quite promising results with estimated yields of ~7E-4 K/proton. Monitored beams can reduce the presently large cross-section uncertainties to the 1% level.**

- **NuTag beam-line first design developed for a “double polarity”, while the “single polarity” option also needs to be studied allowing possibly higher rate @ near & far detectors**

- **Synergies between the two projects are being investigated within the framework of CBWG-NB**


CERN