The design of the beamline for the ENUBET experiment

Claudia Caterina Delogu
University of Padova & INFN
on behalf of the ENUBET Collaboration

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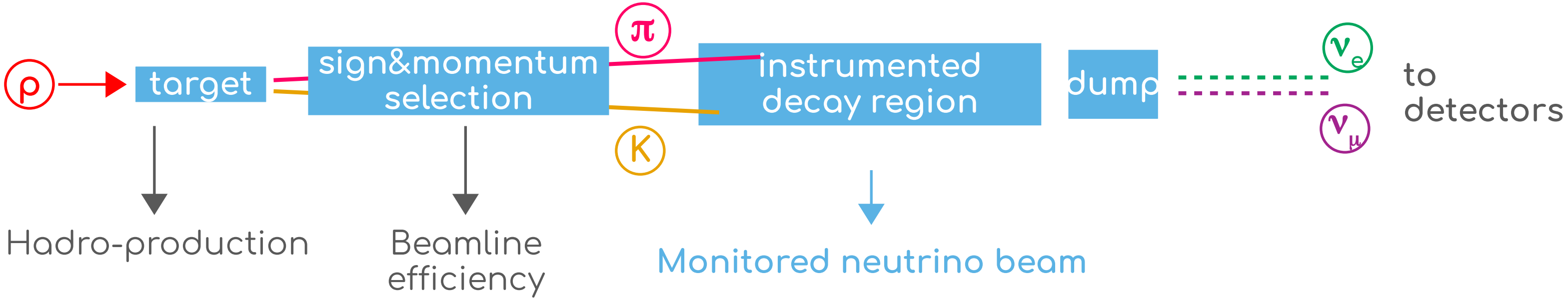
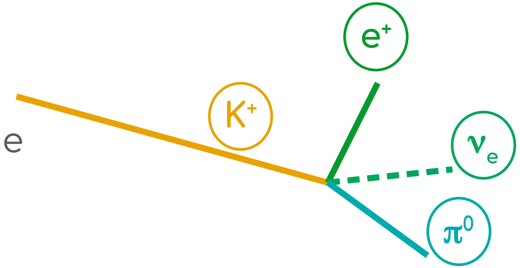
NP06/ENUBET: Enhanced NeUtrino BEams from kaon Tagging



→ O(10%) flux uncertainty



Novel ν_e source from $K^+ \to e^+ \pi^0 \nu_e$ decays, lepton production at large angles is monitored at single particle level by calorimetric techniques, i.e. tagging the e^+ in an instrumented decay pipe

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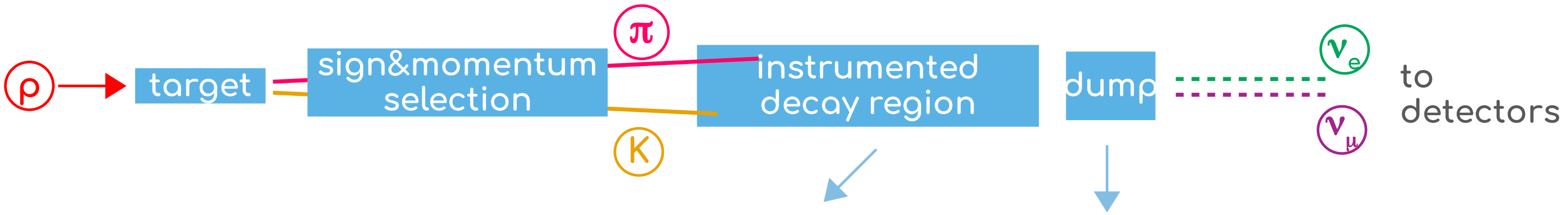


Positrons from: $K^+ \rightarrow \pi^0 e^+ \nu_e$

Muons from: $K^+ \rightarrow \mu^+ \nu_\mu$, $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu$

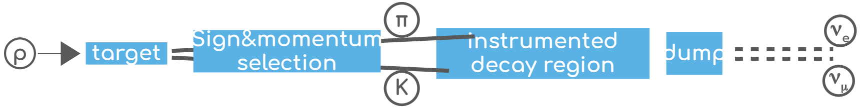
Muon monitoring

$\pi^+ \rightarrow \mu^+ \nu_\mu$

Design optimized to reach a O(1%) precision on the ν_e flux → ν_e flux prediction = e^+ counting

Two main steps:

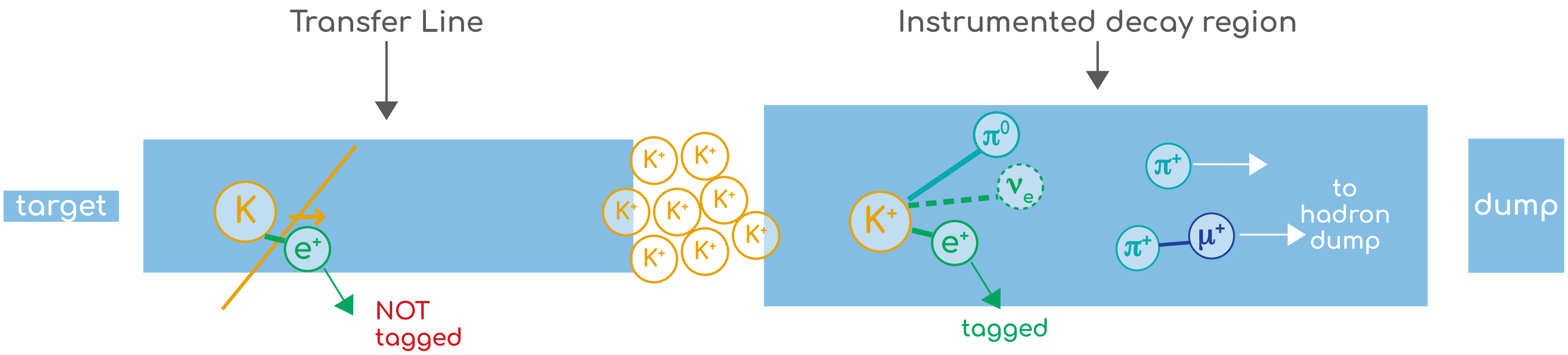
- layout of the π/K focusing and transport system with suitable proton extraction schemes
- special instrumented beamline capable of performing positron monitoring from decays of K in a ν beam decay tunnel at single particle level

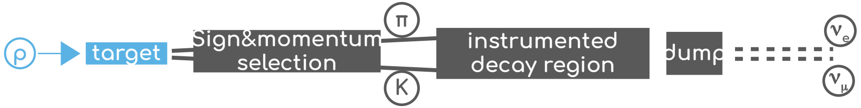


The Beamline

Requirements:

- Use of **conventional magnets** (normal-conducting, aperture < 15 cm)
- Keep under control level of **background** transported to the tunnel: fine tuning of **shielding and collimators**
- **Maximize** number of K^+ **at tunnel entrance** (looking for $K^+ \to e^+ \pi^0 \nu_e$)
- **Small beam size**: non decaying particles should exit the decay pipe without hitting the walls
- Minimize total length of the transferline (~20 m) to **reduce kaon decay** in the **not instrumented region**





Proton target design

Optimum particle production: primary proton beam = **400 GeV**, secondary kaons momentum ~**8.5 GeV**.

Goal: **maximise K** production in region of interest.

- Optimization of transverse dimensions and length
- Test of different materials (Graphite, Beryllium, Inconel)

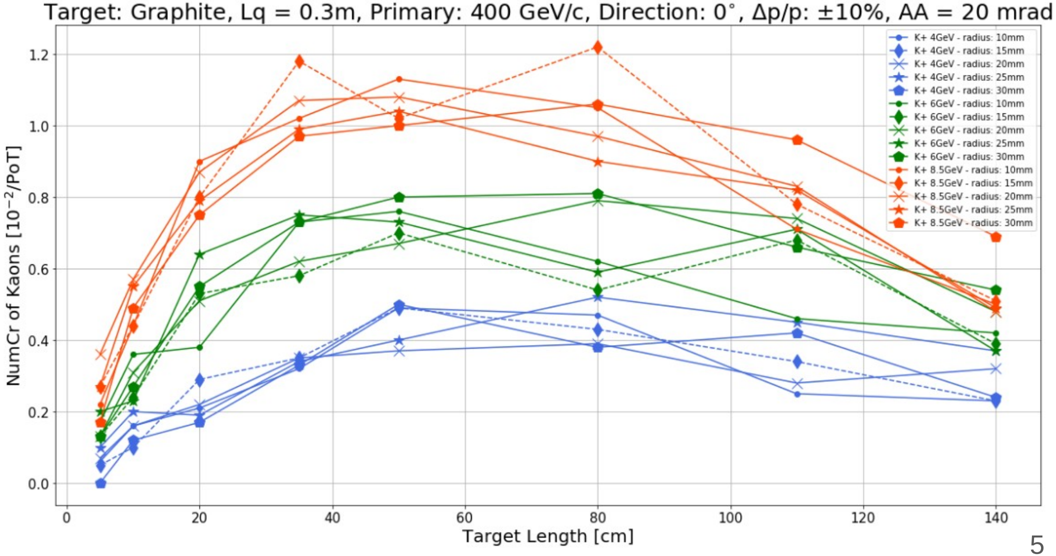
FLUKA + **G4beamline** simulations

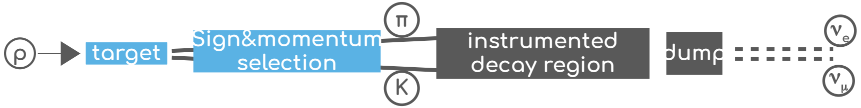
→ maximise number of kaons of given energy (10% momentum bite) that enter a beamline with 20 mrad angular acceptance

Last version of the beamline:
Graphite target, L = 70 cm, R = 3 cm

Inconel target (L = 50 cm, R = 3 cm) is also being considered

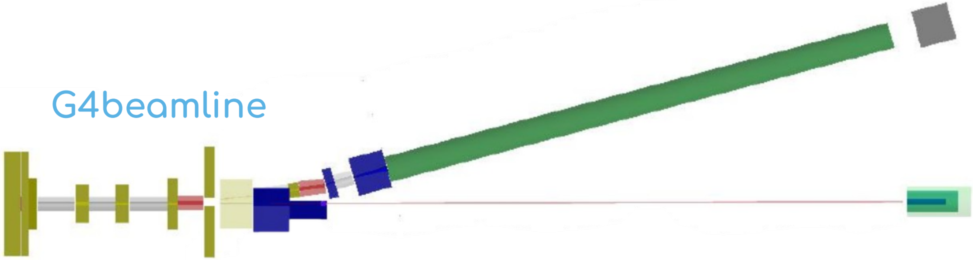
Graphite target radius scan



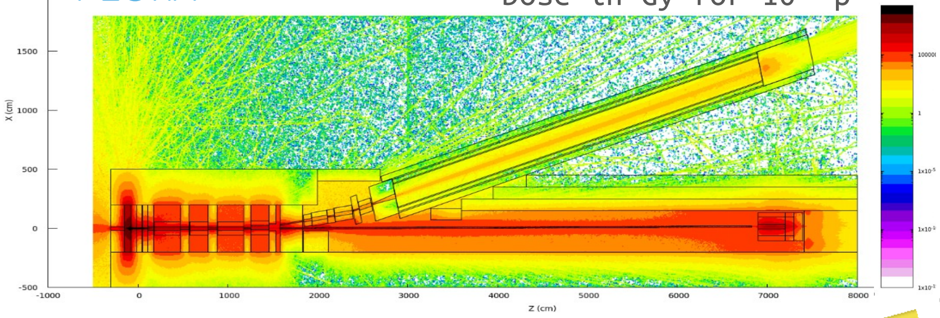


Transfer Line design

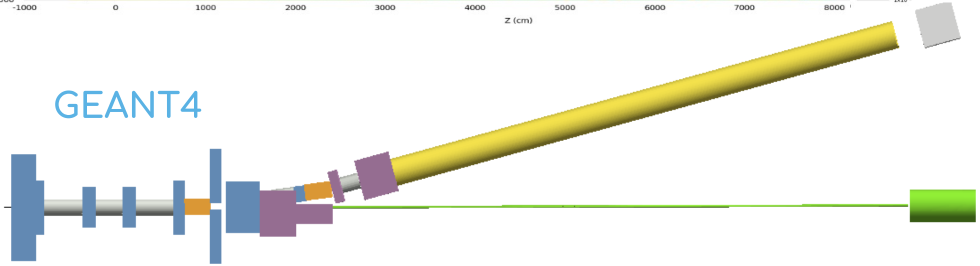
G4beamline



FLUKA



GEANT4



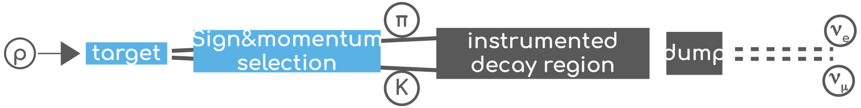
Static TL, top view

Optics optimized with **TRANSPORT**.

Particle transport and interaction: full simulation with **G4beamline**

FLUKA: assess doses in the tunnel area where instrumentation will be placed, target studies

GEANT4: optimization of beamline elements, systematic uncertainties on the neutrino flux



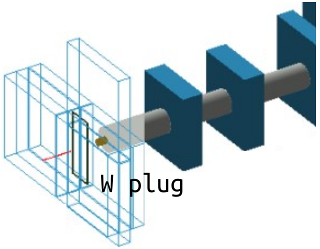
Transfer Line details

Reference beamline: 8.5 GeV, 10% momentum bite.
Focusing system: a quadrupole triplet before the bending magnets (14.8° bending)

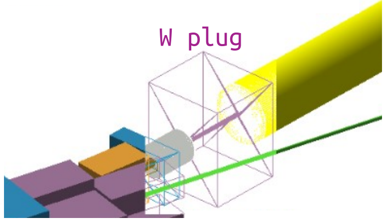
→ Larger bending angle (w.r.t. original proposal) and increased length

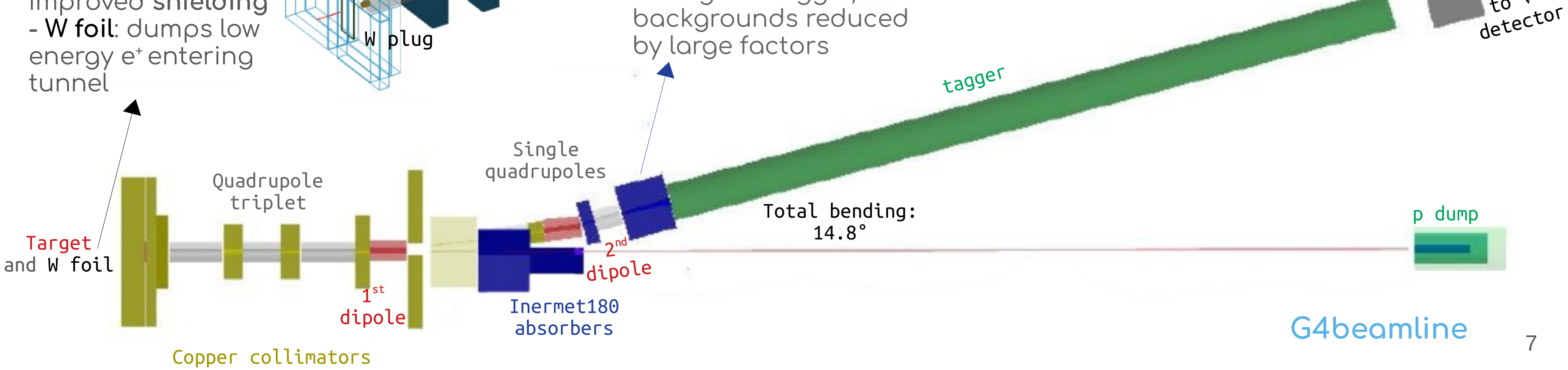
→ Better collimated beam and reduced backgrounds

Improved **shielding**
- **W foil**: dumps low energy e^+ entering tunnel

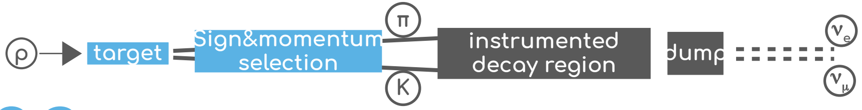


Improved **shielding**
- **W plug**: dumps low energy particles hitting the tagger, backgrounds reduced by large factors





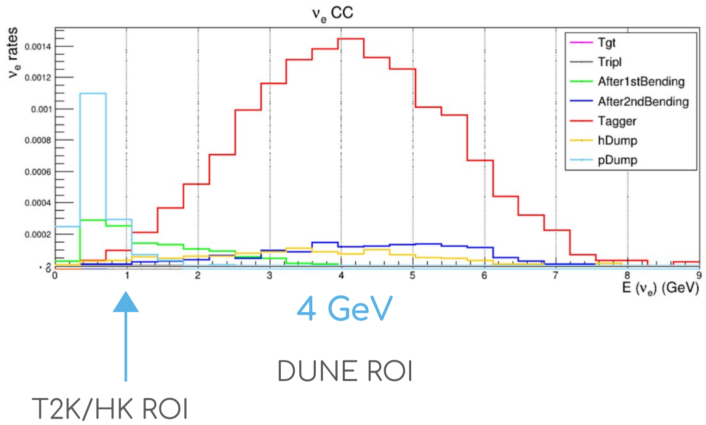
G4beamline



Multi Momentum beamline

Neutrinos from reference beamline are peaked ~4 GeV (DUNE R.o.I, Region of Interest).

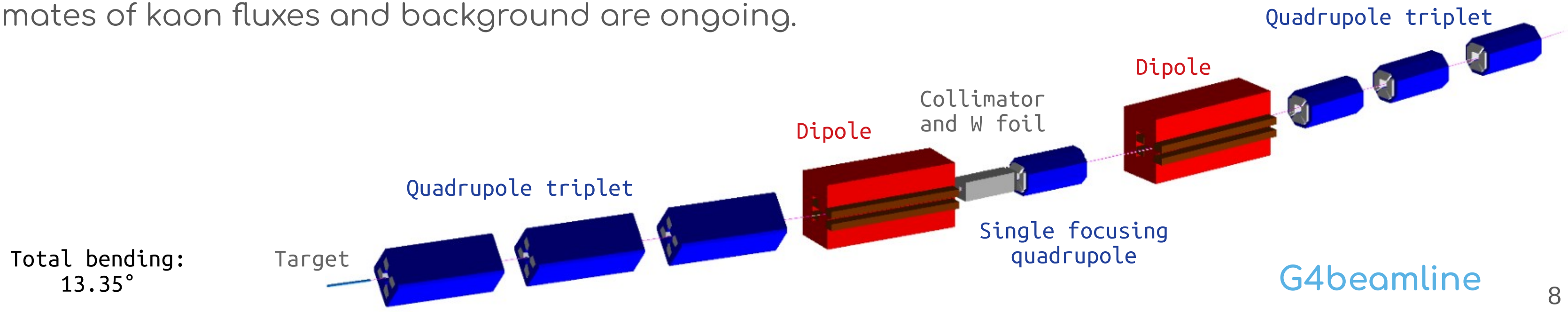
New beamline design: secondary multi momentum (4, 6, 8.5 GeV) → cover full range of interest (including the low-energy region, T2K/HyperK R.o.I.)

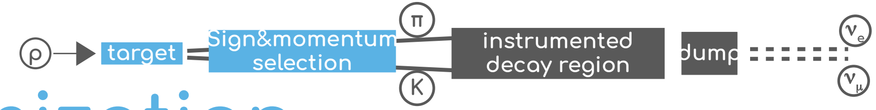


Optics optimization: **TRANSPORT, G4beamline**.

Contains detailed description of existing magnetic elements

First estimates of kaon fluxes and background are ongoing.





GEANT4 - beamline optimization

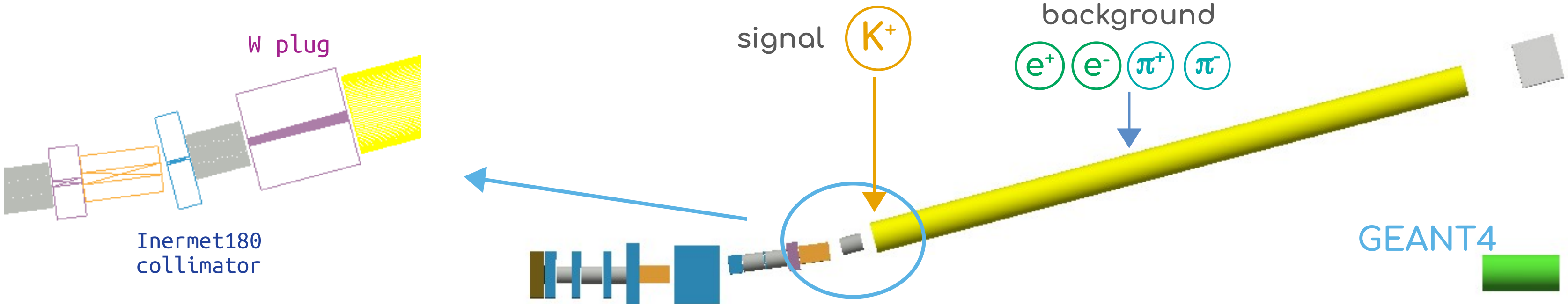
New design from **G4beamline** (feat. new proton target) → suppression of low energy ν_e from target region

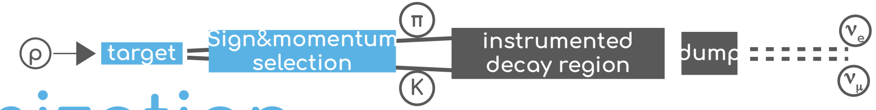
Further reduction of background: optimization and final design of collimators and absobers at the end of the transfer line (position, dimension and apertures) in progress with **GEANT4**

→ New genetic algorithm implemented to sample the parameter space

- Convergence in O(100) iterations
- Figure Of Merit = ratio $K^+_{\text{entering tagger}}$ / background$_{\text{hitting tunnel}}$ (bkg = e^{+-}, π^{+-})

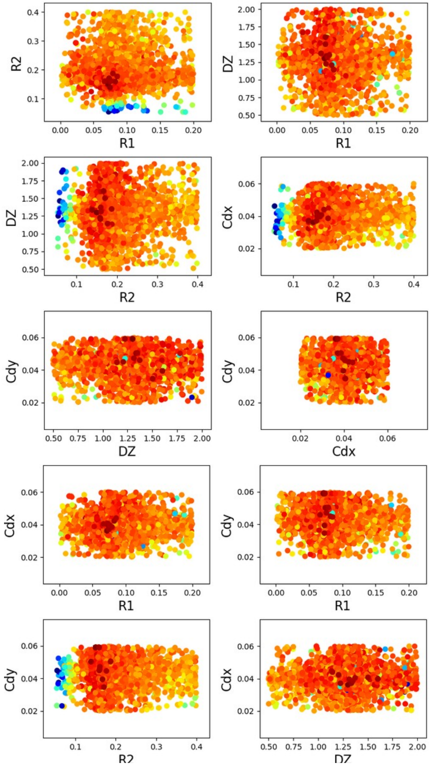
  = signal/background to be maximized



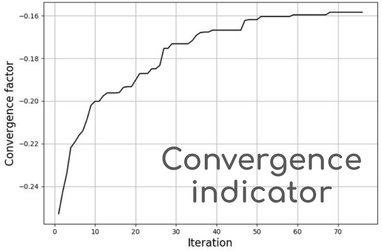


GEANT4 - beamline optimization

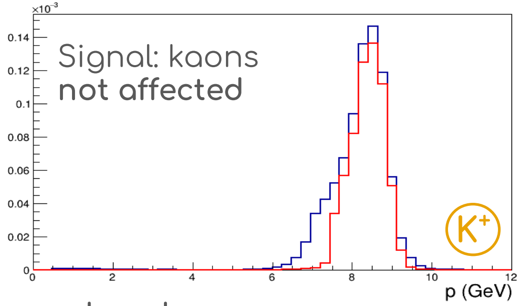
→ FOM = ratio $K^+_{\text{entering tagger}}$ / background$_{\text{hitting tunnel}}$



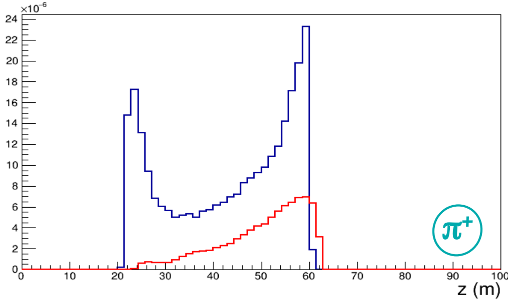
Scan of parameter space with FOM value in colour scale

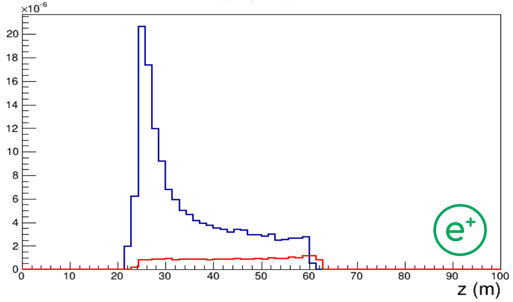


Preliminary

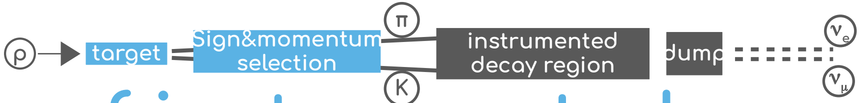


Background: pions and positrons - **reduced**





Before implementation of new collimators
After optimization



Particle fluxes @ entrance of instrumented decay region

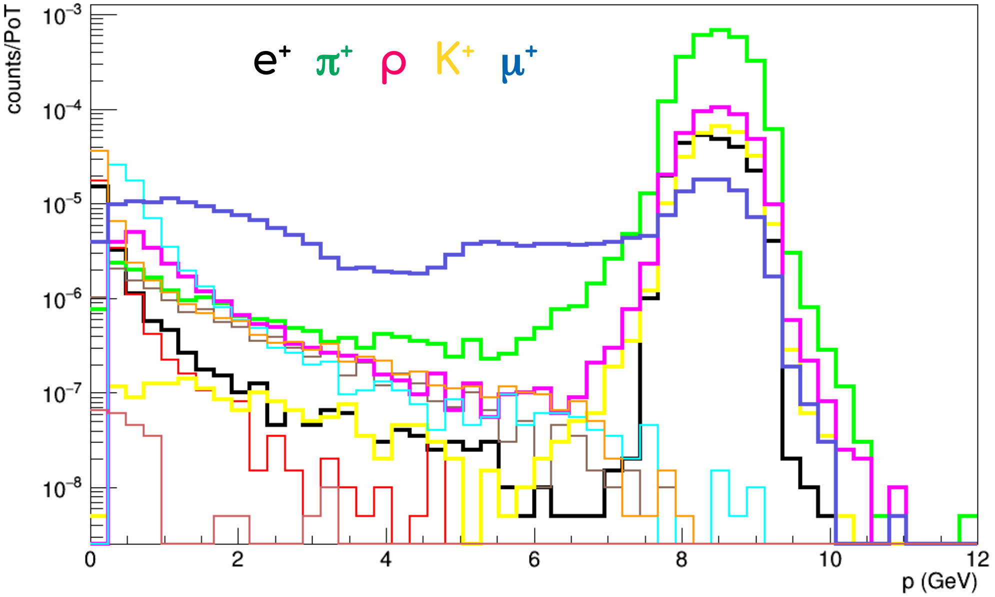
GEANT4 reproduces geometry and outcome of G4beamline simulation.

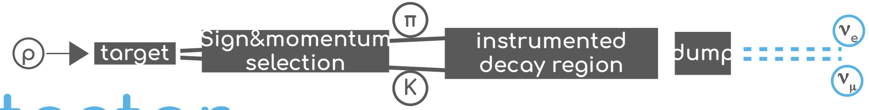
Contains information on particle decay along the beamline.

Flexibility of GEANT4 simulation:

- Map of different kinds of background entering the instrumented decay region
- Optimization of the beamline design
- Study of flux systematics

Spectra of particles at tagger entrance



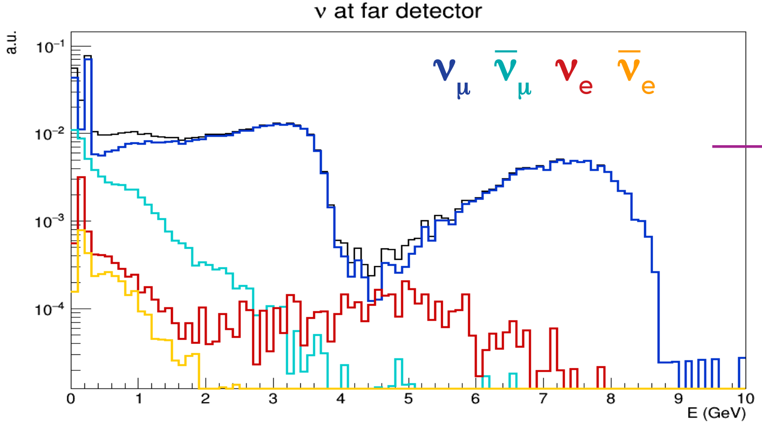


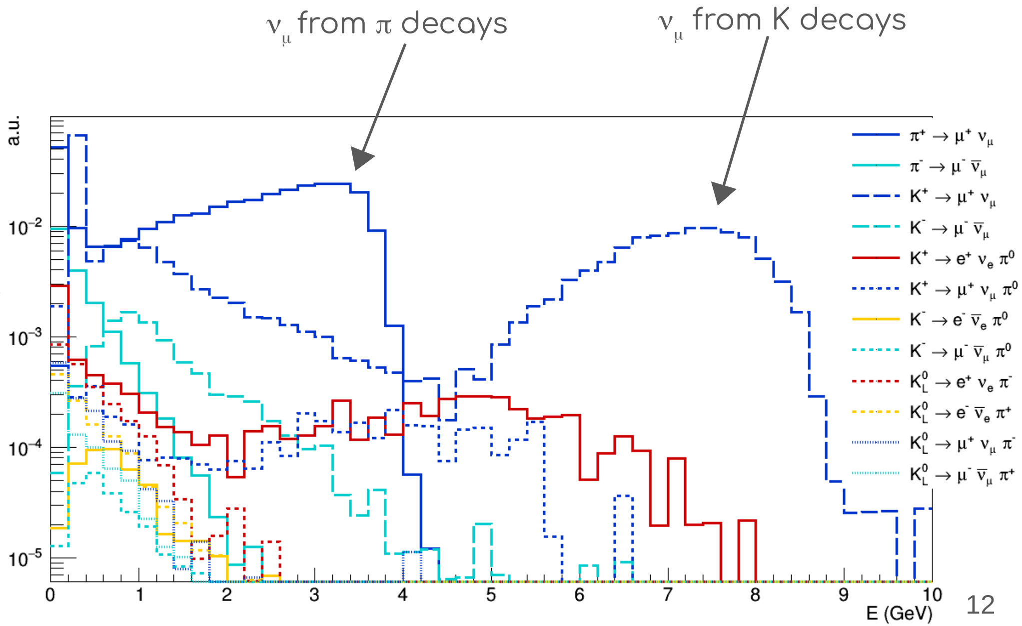
Neutrino fluxes @ far detector

Flexibility of **GEANT4** simulation:

- Detailed definition of signals, generation and path of different neutrino production mechanisms
- Even after instrumented decay region → far detector

Neutrino flux (weighted by energy) on a 6x6m² surface at 70m from the tagger exit





Summary

- ENUBET: reducing the flux related systematics → monitoring charged leptons in an instrumented decay tunnel
- Design of a transfer line: maximize K^+ and π^+ yield, minimize meson decays in the non-instrumented region.
- Step forwards in simulation:
  - Beamline designe
  - Improved proton target design
  - GEANT4 simulation also for optimization studies
  - Doses estimation through FLUKA simulation
  - Multi Momentum beamline (4, 6, 8.5 GeV) → enhanced physics reach
- Next steps:
  - Finalize optimization