WP4: Software tools

Francesco Collamati, Michele Gallinaro

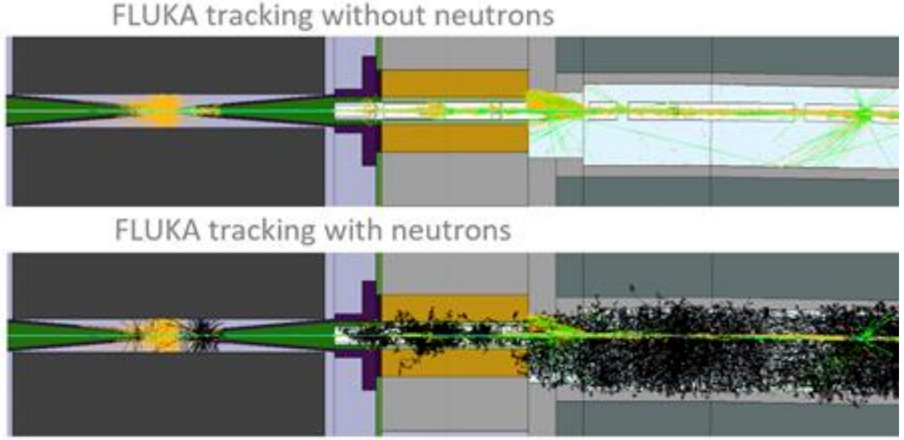
INFN-Roma and LIP/IST-Lisbon

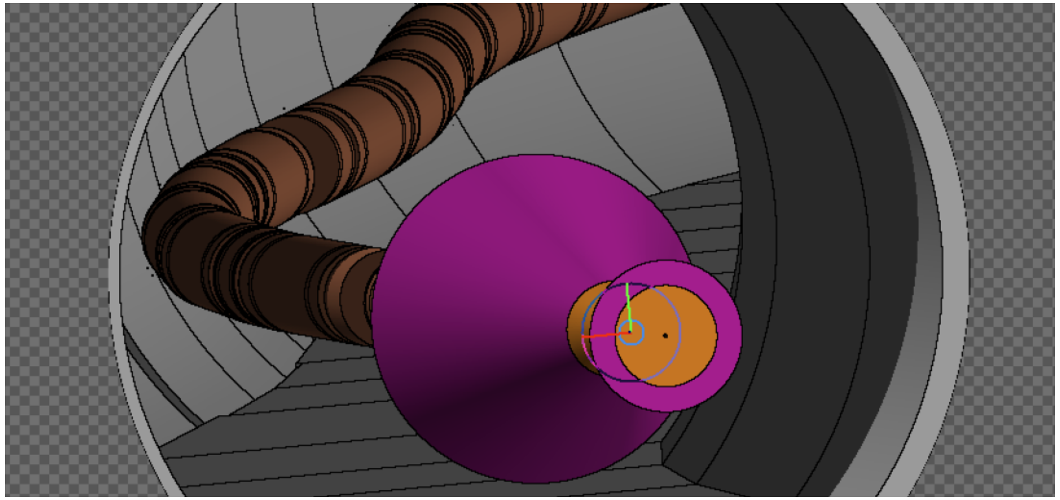
WP4 - Tasks

- Task 1: Simulation of the interaction and transport of particles and nuclei
- Task 2: Simulation of muon beams and detectors
- Task 3: Deep Learning techniques applied to data analysis
- Task 4: Deep Learning applied to pattern recognition
- Task 5: LFV models and software package

Task 1: Particle transport

- Simulation of interaction & transport of particles and nuclei in matter
  - A framework was **developed** to map the interaction region (IR) design of high energy muon beams into FLUKA simulations
  - Interaction of muon beams with machine elements **simulated** to generate the beam-induced background (BIB)
  - In order to optimise the machine layout, the code is **flexible** to modify the machine lattice and re-generate the background
  - The same framework can also be used to simulate the hazard due to the neutrino-induced radiation**,** or to **study physics issues**



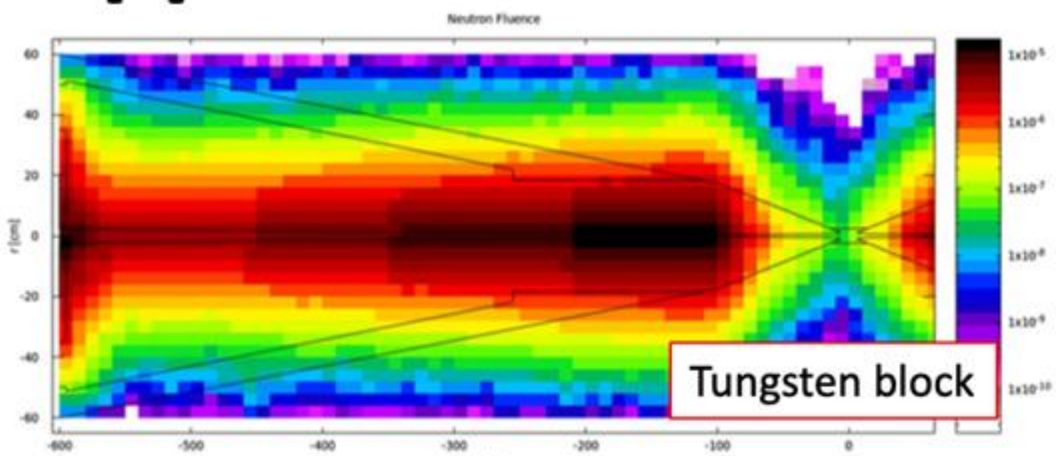


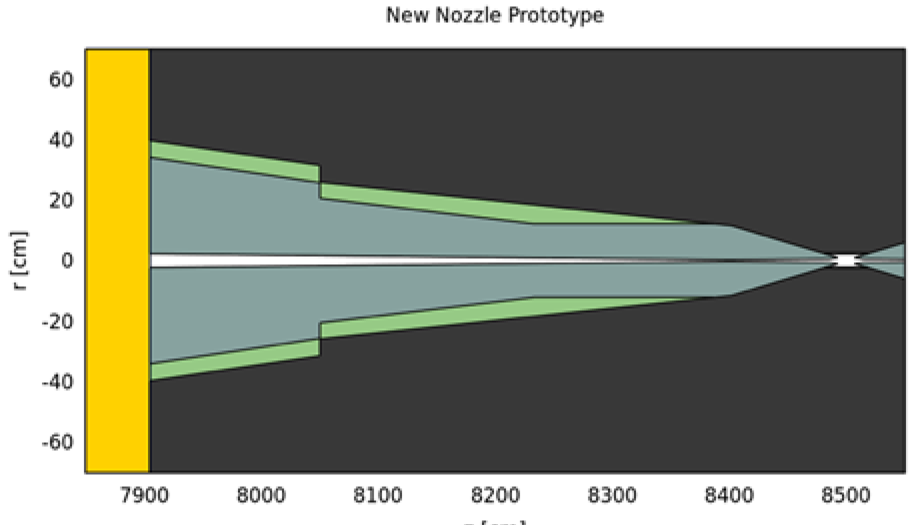
Task 2: Beam and detector simulation

- Simulation of muon beams and detectors (synergic with WP3)
  - Develop framework to include simulation of BIB and design a detector able to cope with high-energy muon beams

    ⇒ Unified software platform (INFN-CERN)
  - Tune the detector design as function of center-of-mass energy

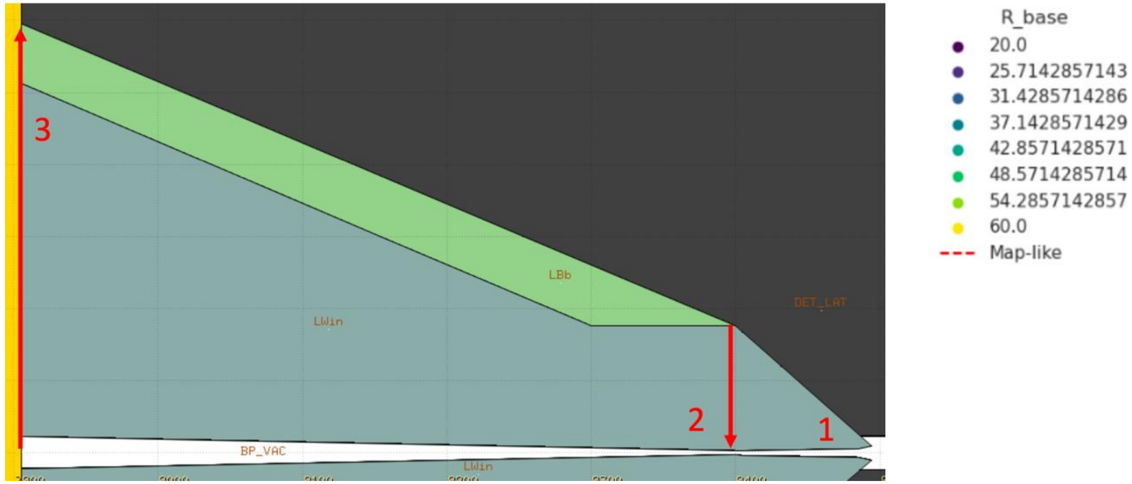
    ⇒ studying beam optics, detector magnetic field, **nozzle geometry** and impact on beam dynamics





Task 2: Beam and detector simulation

- Nozzle Design Optimization
  - **Machine Learning Approach**
  - »By hand» optimization



Procedure:

- 1200 simulation each with a different Nozzle configuration
- Fluka output reconstructed in the Detector (no digitization)
- Regression to parametrize the occupancy in the first layer of the Vertex Detector as function of:

1. $\theta tip \in [3.8; 10]°$
2. $|zchange| \in$ 50; 200 cm
3. $r\ base \in$ 20; 60 cm

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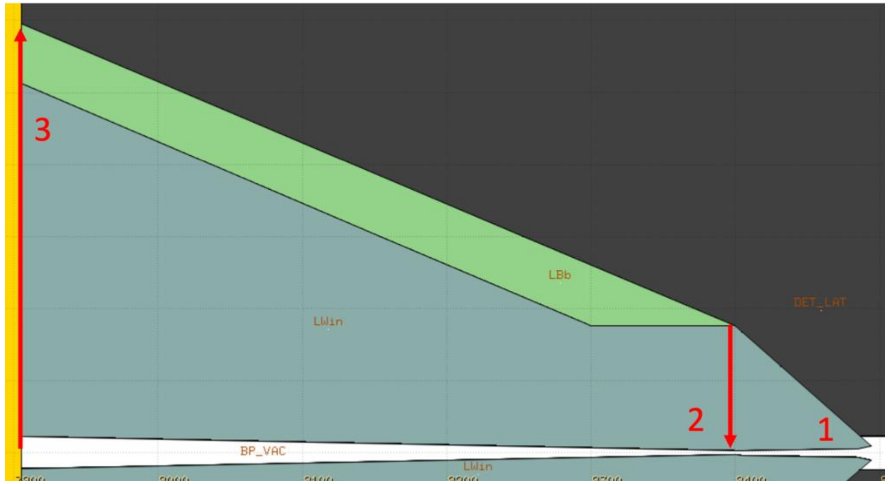

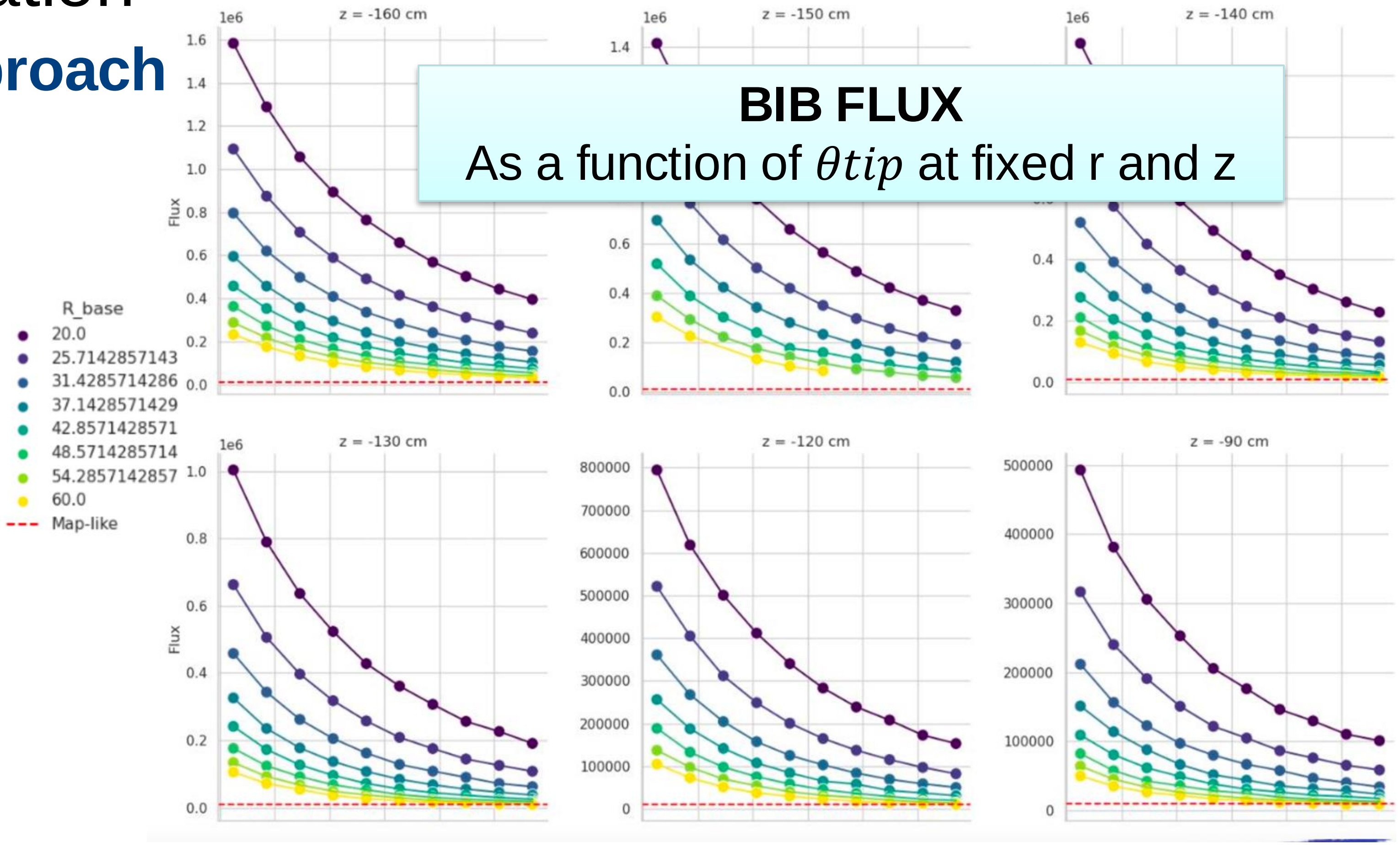

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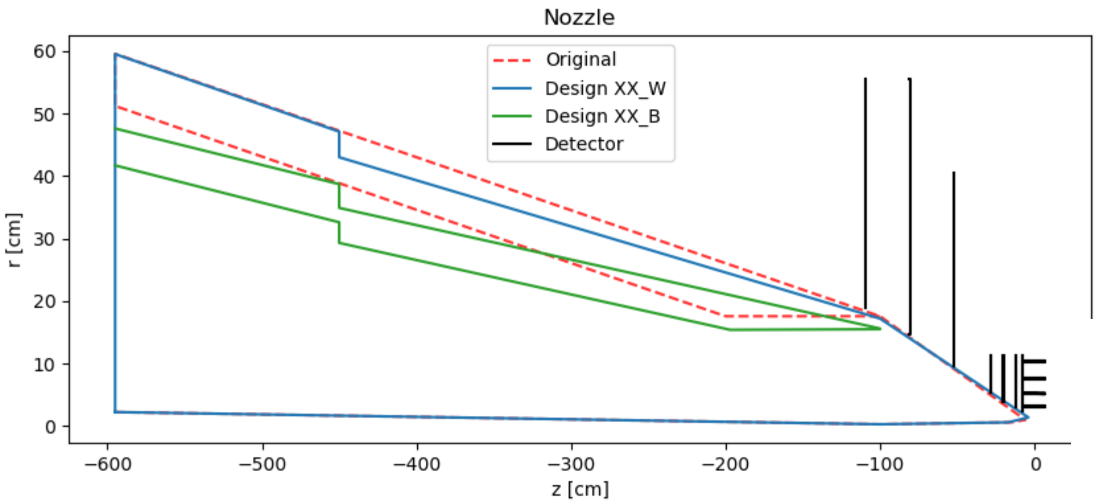
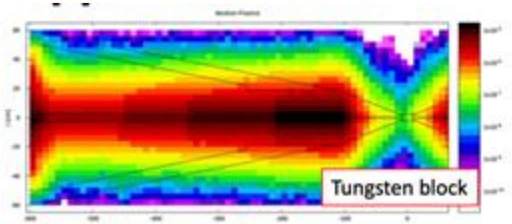
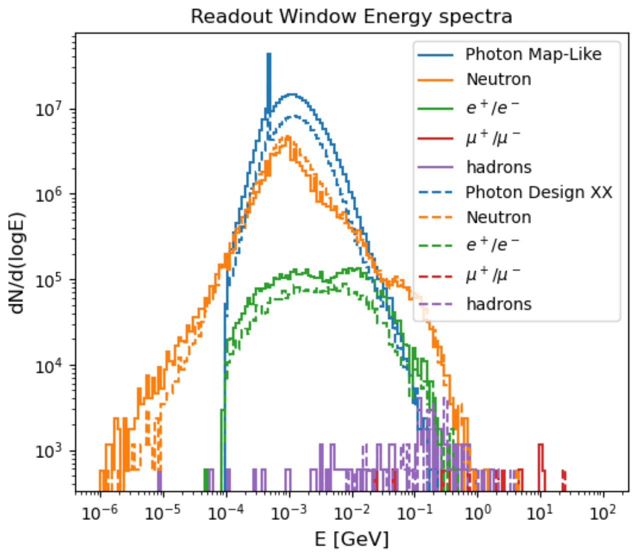
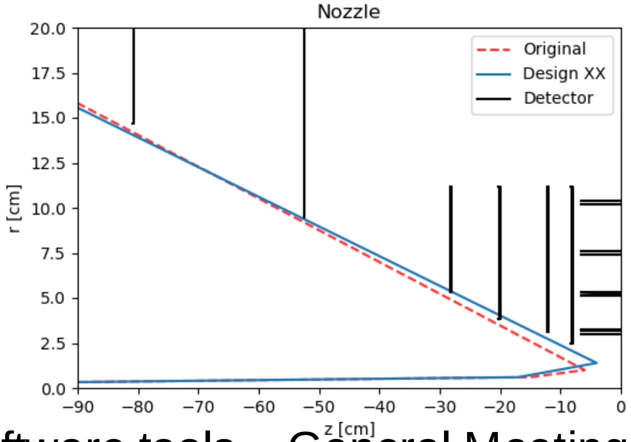
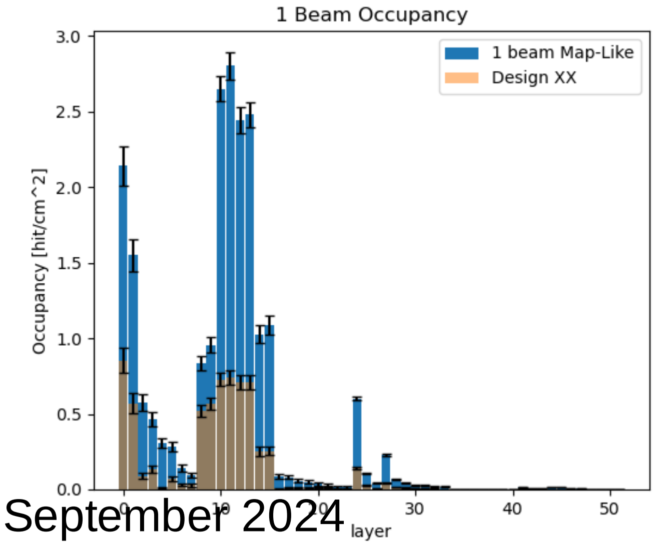




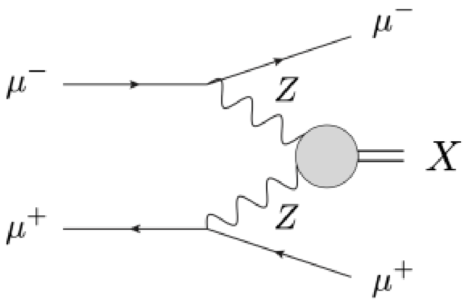


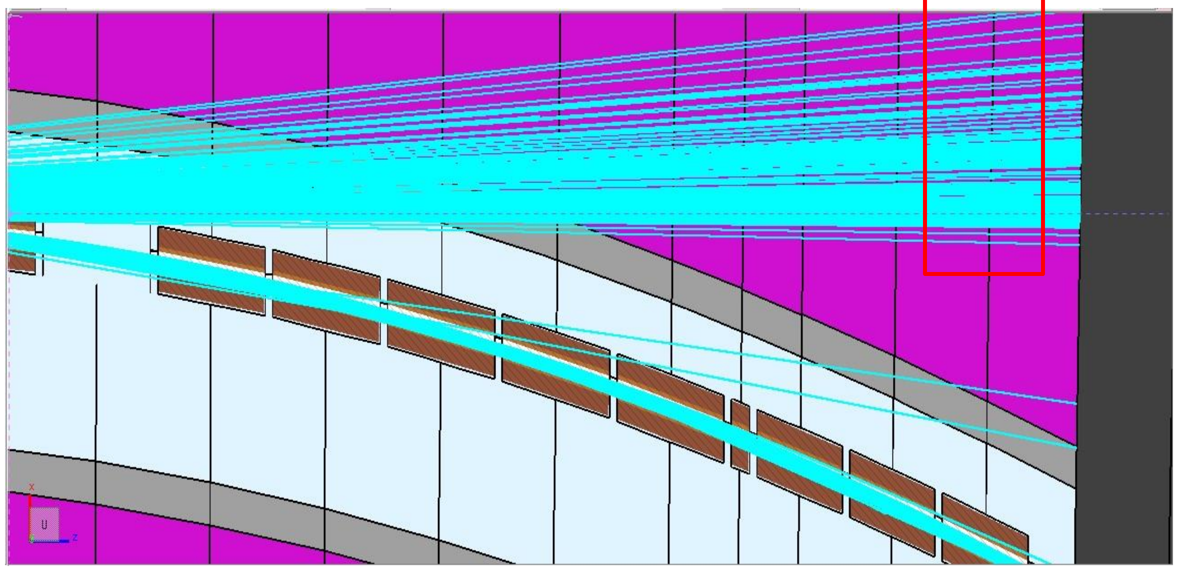


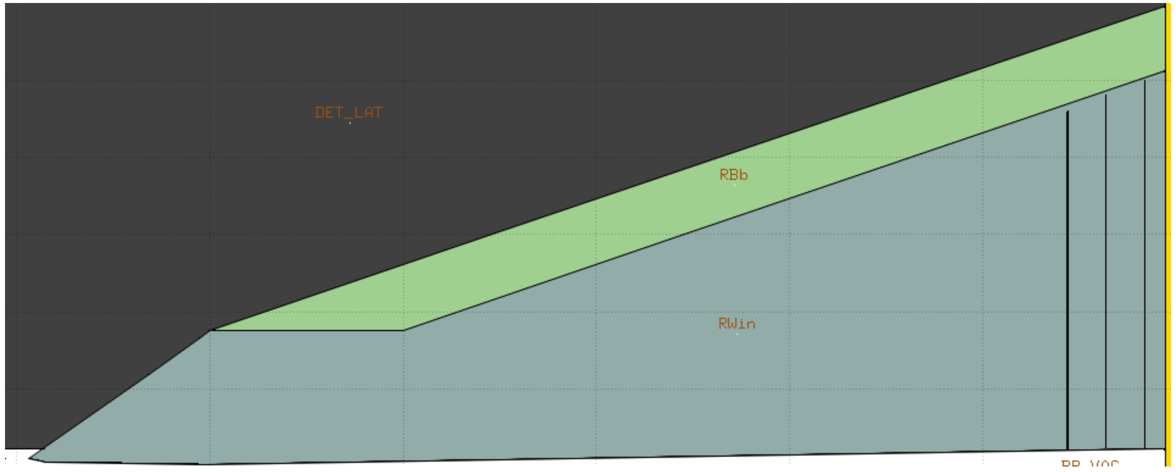


Task 2: Beam and detector simulation

- Example of possible interesting physics study: **Forward Muons**
  - **Why interesting**?
    - Allows to distinguish process from Z/W boson fusion
    - Allows precise measure of Higgs boson Width [2, 6]
    - New physics might have forward muons in the final state [3]





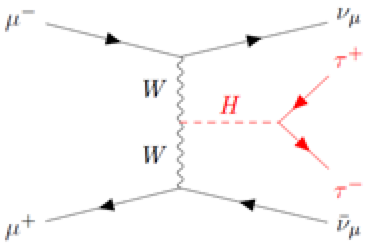


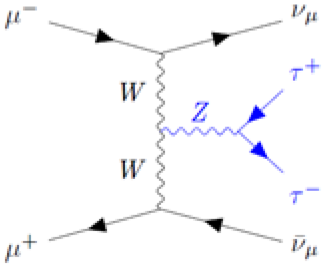
Task 3-5: DL and data analysis

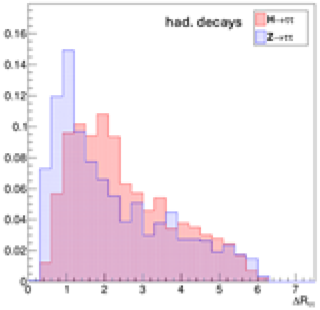
- Deep Learning (DL) techniques applied to data analysis
  - The **incredible** amount and **complexity** of the **data** arising from particle interactions **require advanced tools**
  - Develop statistical methods suitably designed
  - Investigate use of **advanced DL methods**, and statistical nonparametric or semiparametric models to account for the specificities of the data in each specific problem
  - Include specific physics studies of relevant processes *(Higgs, Top, B, EWK, SUSY, DM, etc.)* to probe the sensitivity of the experiments to SM parameters and probe of New Physics

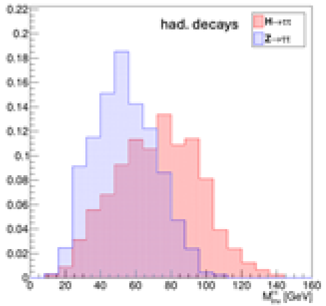
Task 3-5: DL and data analysis

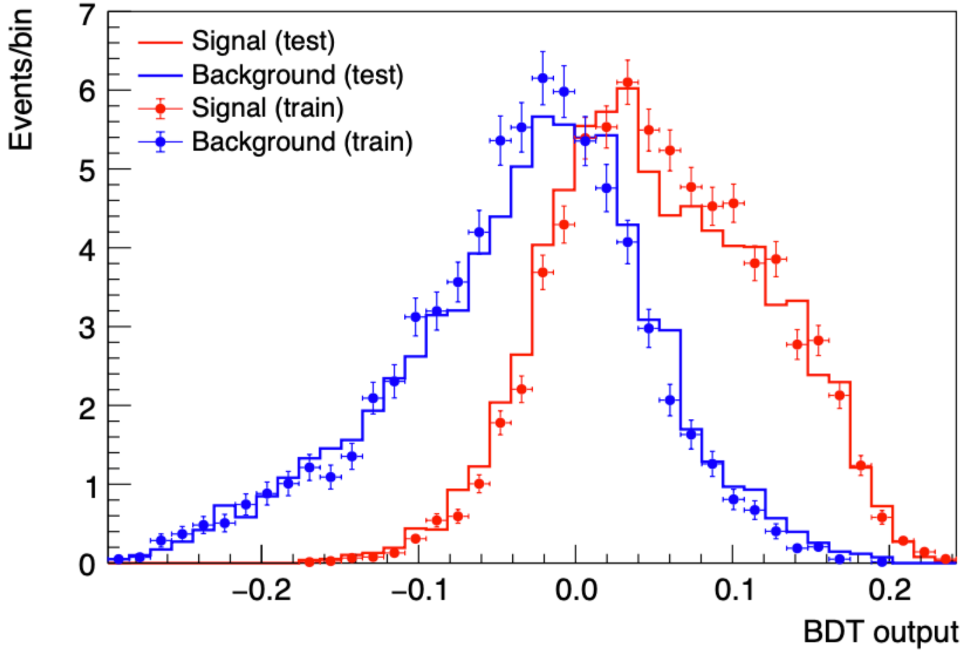
- Tau lepton identification
  - Case study: **Higgs** production **at 3TeV** Muon Collider: H→ττ
  - Discriminate signal from background (mostly Z→ττ)
  - Detector simulation, digitization, event reconstruction with Marlin, default detector configuration
  - *TauFinder*: define τ seed, identify charged/neutral particles in signal cone





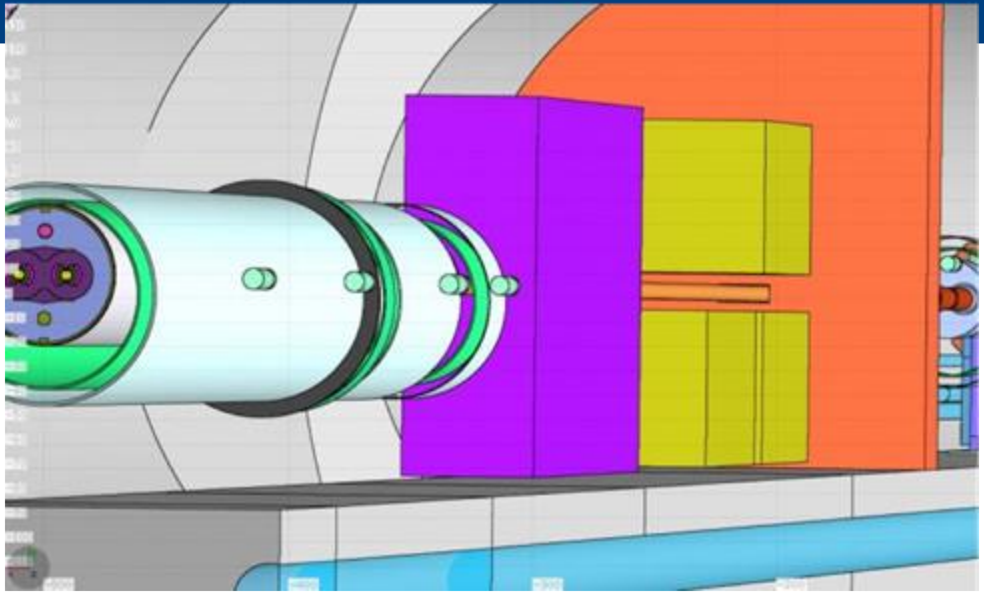


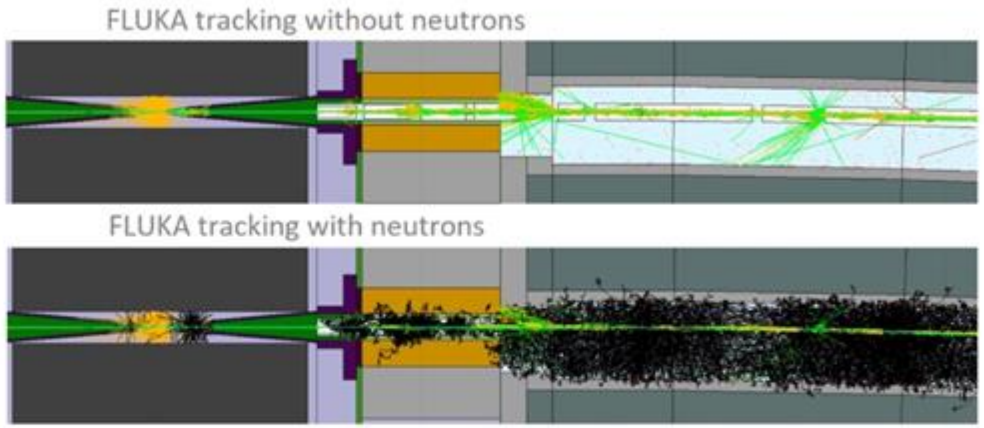




WP4 - Deliverables

- D4.1 (#18): Release of software package interfacing FLUKA with IR lattice and beam-induced background ⇒ completed
  - CERN and INFN software tools merged
  - Unified “Line Builder” software
  - Flexible and updated tools
- D4.2 (#28): Simulation implementation of high-energy muon beams, detector and BIBs in software package ⇒ completed
  - Beam generation, transport to IP simulated at 3 TeV
  - Adding second beam for collision
- D4.3 (#40): Report on the application of ML tools to aMUSE activities
  - LFV studies with muons and tau decays
  - Higgs studies





Summary

- WP4 provides a synergic interaction of expertise among all network participants
- Focus on common tools and resources
- Common software and advanced analysis technique to perform physics sensitivity studies (Higgs, Electroweak, Flavour, etc)

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Task 3-5: A few examples

- FlexibleSUSY: generator plus observables for arbitrary models
- GM2Calc: dedicated high-precision computation of g-2 in SUSY and 2HDM models
- Developed new tool to incorporate new cLFV observables in *FlexibleSUSY* [2206.00745]
  - Application to neutrino mass models [2206.00661, 2211.14384]
  - Impact on 2HDM Higgs sector from μ→eγ bounds, and LQs [2305.05016]
  - In … m a_μ and μ→eγ