MUON BACKGROUND STUDIES FOR BEAM DUMP OPERATION OF THE K12 BEAM LINE AT CERN

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ENGINEERING DEPARTMENT

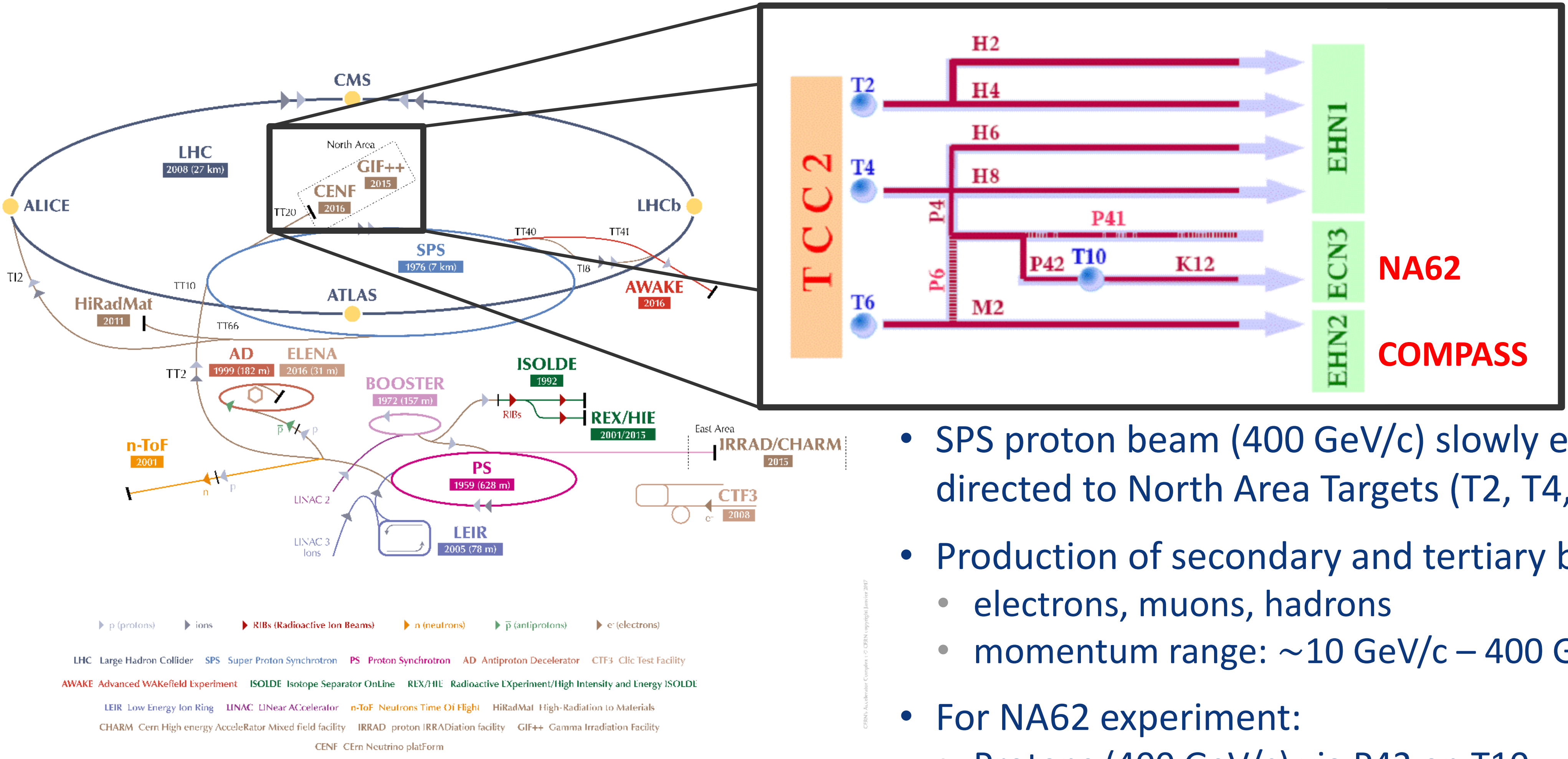
Introduction

- The NA62 experiment is located in experimental cavern ECN3 in the North Area of CERN
  - Goal: Measurement of branching ratio $K^+ \rightarrow \pi^+ \nu\bar{\nu} \quad \mathcal{O}(10^{-10})$ with a precision < 10%
  - 400 GeV/c protons of SPS interact with Be-target to create required kaon beam

- Physics Beyond Colliders Study at CERN:
  - Explore the opportunities offered by the CERN complex, complimentary to high-energy colliders
  - Various proposals are investigated, e.g. the operation of NA62 in beam dump mode

- NA62 - Beam Dump:
  - Production of hypothetical dark sector particle by primary protons dumped on massive copper/iron block
  - Observe decay products, e.g. muons, in NA62 experimental setup
  - Simulation and mitigation of muon background crucial.

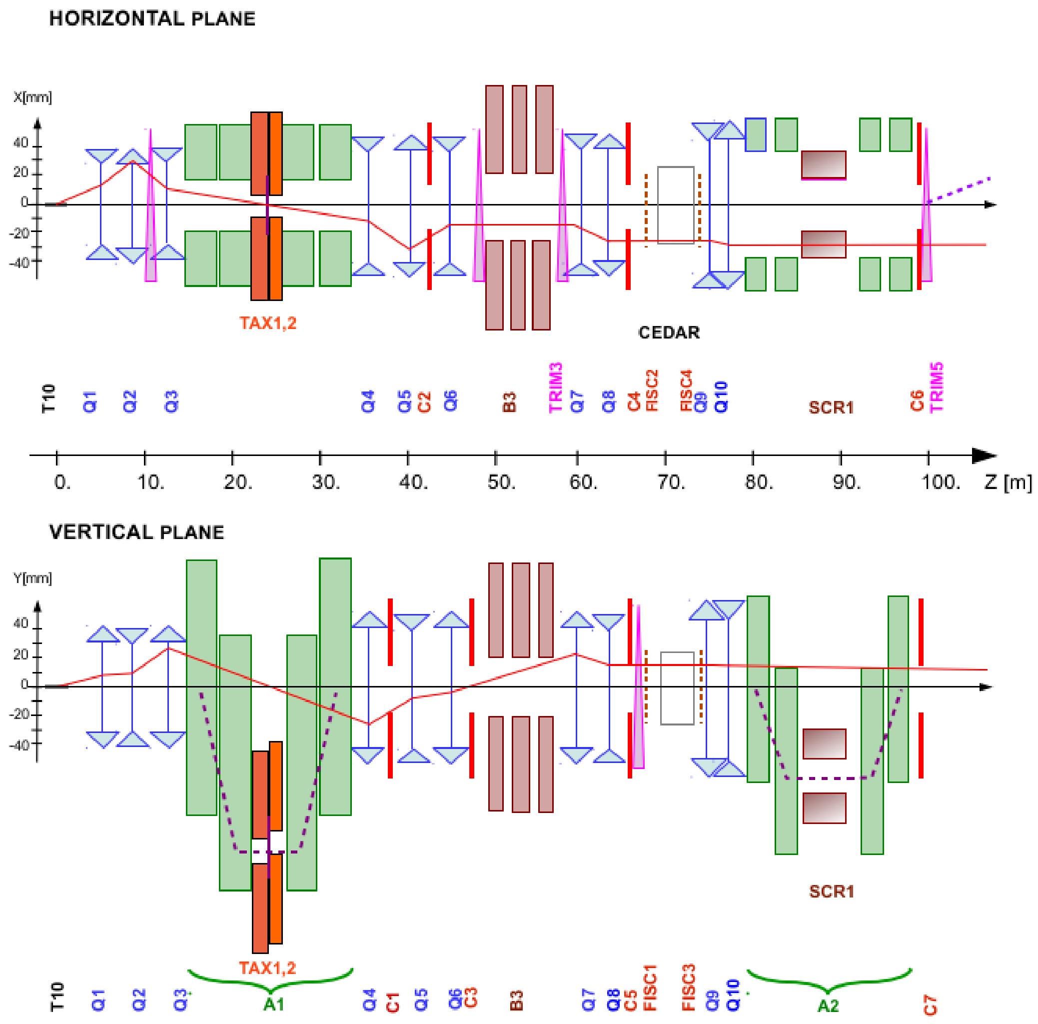
North Area of CERN



- SPS proton beam (400 GeV/c) slowly extracted and directed to North Area Targets (T2, T4, T6, T10)
- Production of secondary and tertiary beams
  - electrons, muons, hadrons
  - momentum range: ~10 GeV/c – 400 GeV/c
- For NA62 experiment:
  - Protons (400 GeV/c) via P42 on T10
  - Secondary hadron beam (75 GeV/c) in K12

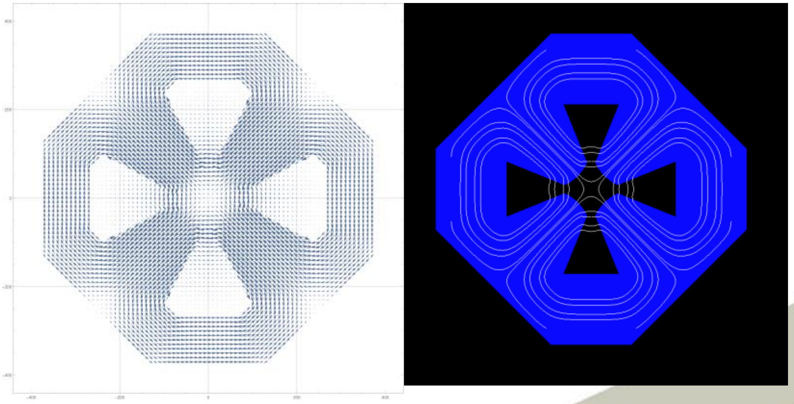
The K12 Beam Line

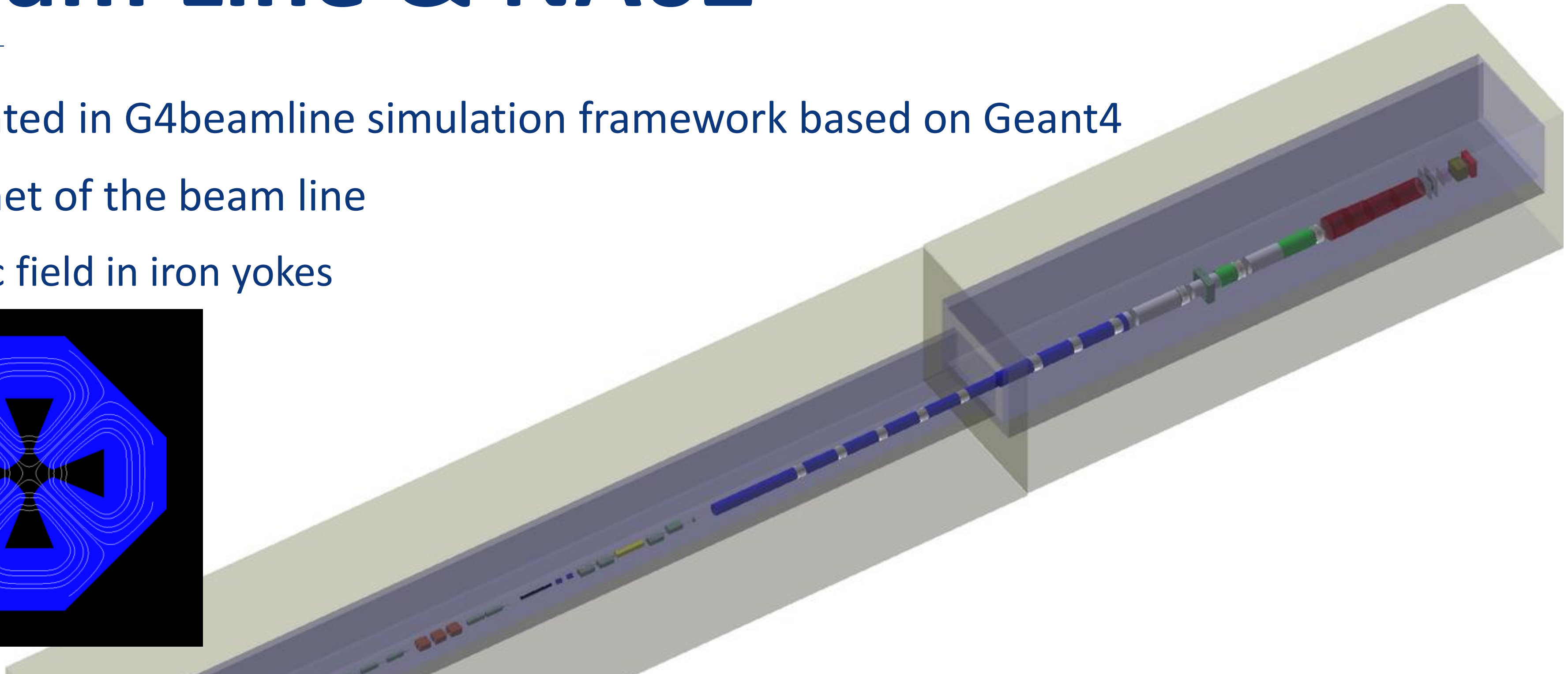
- 400 GeV/c protons impinge on 40 cm Beryllium target
  - Shower of secondary particles (p, π, K, e …)
  - π & K decays introduce μ component
- Beam line optics optimized for transfer of positively charged particles of 75 GeV/c
  - Q1-Q3: acceptance (x:$\pm$1.5 mrad, y: $\pm$2.7 mrad)
  - Momentum selection by massive dump collimator TAX
    - 75 GeV/c fraction vertically shifted and selected by 10 mm holes in TAX
    - 400 GeV/c protons dumped on TAX
    - Electrons removed by 4 mm tungsten absorber
- Muon Sweeping Elements
  - B3: Horizontally deflecting bends with field-free region for secondary beam
  - SCR1: Toroidal field for muon deflection

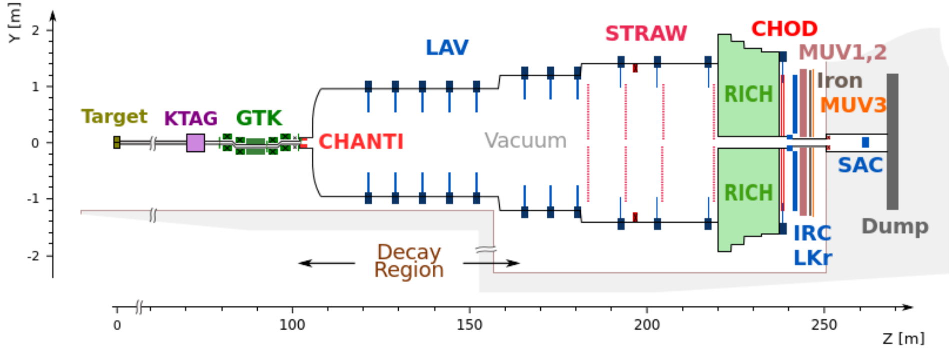


The K12 Beam Line & NA62

- Full beam line implemented in G4beamline simulation framework based on Geant4
- Field map for each magnet of the beam line
  - Also including magnetic field in iron yokes







- Simplified model of the detector geometry of NA62

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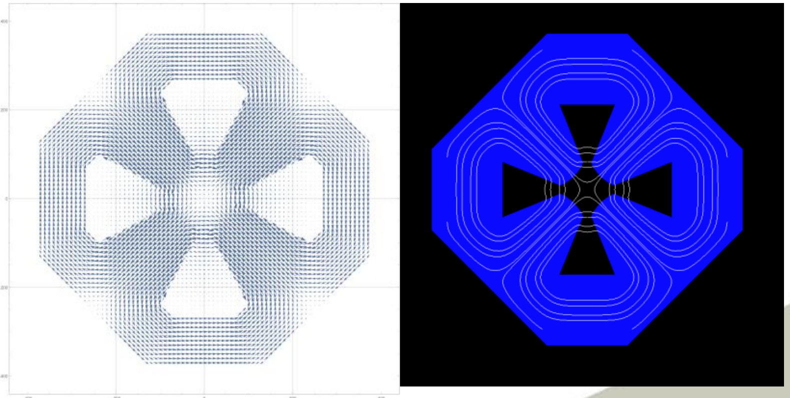
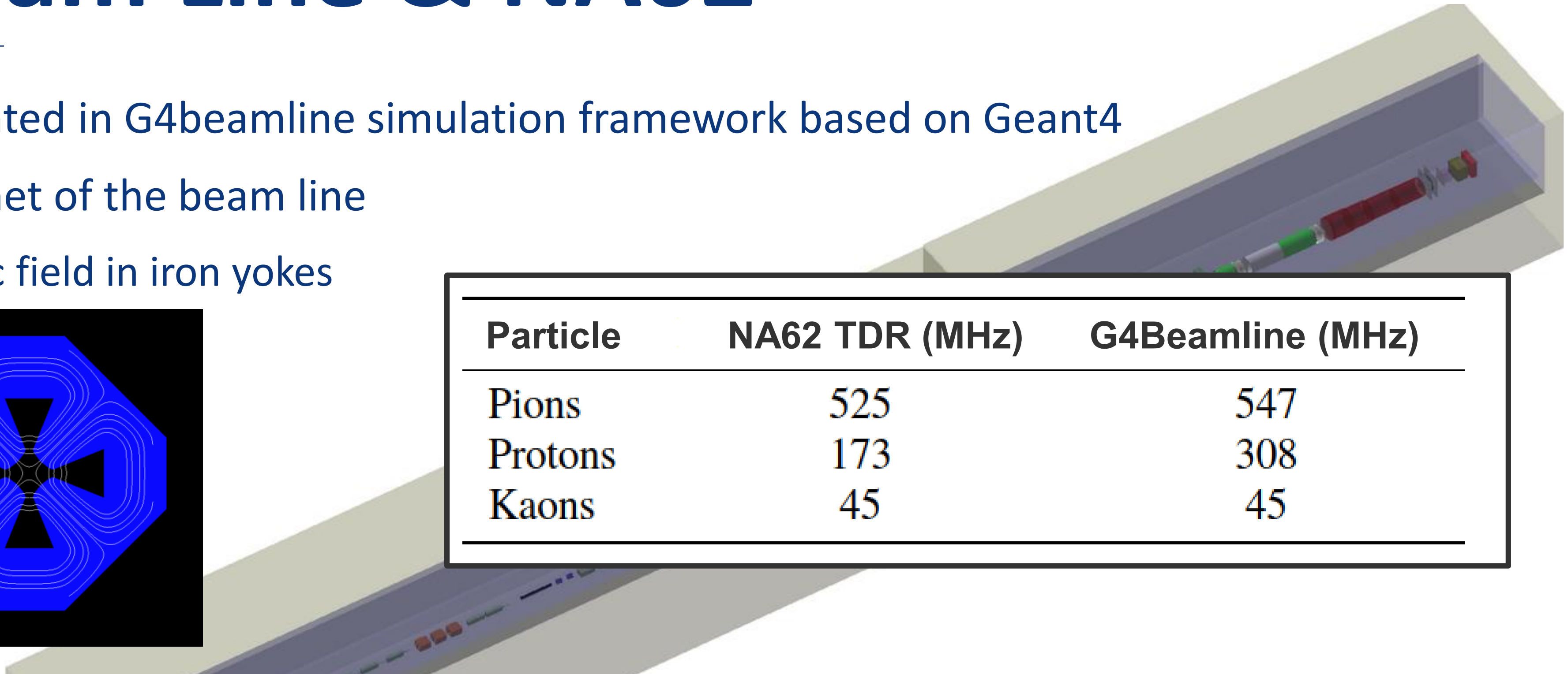
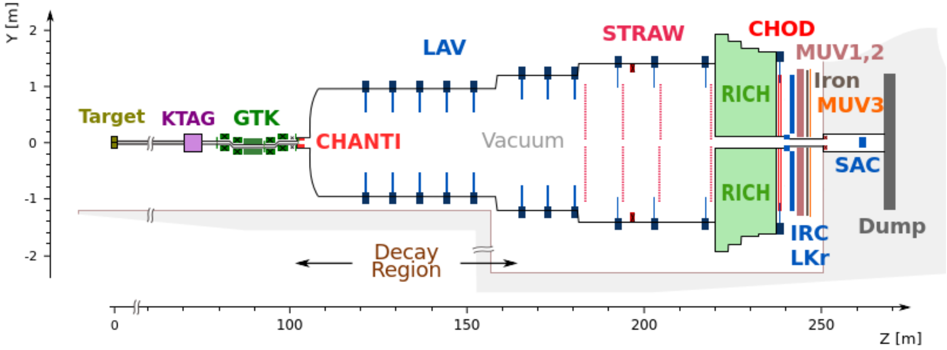




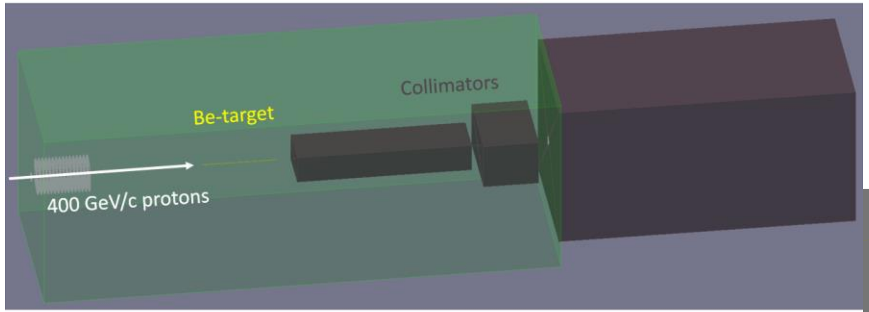
Particle	NA62 TDR (MHz)	G4Beamline (MHz)
Pions	525	547
Protons	173	308
Kaons	45	45

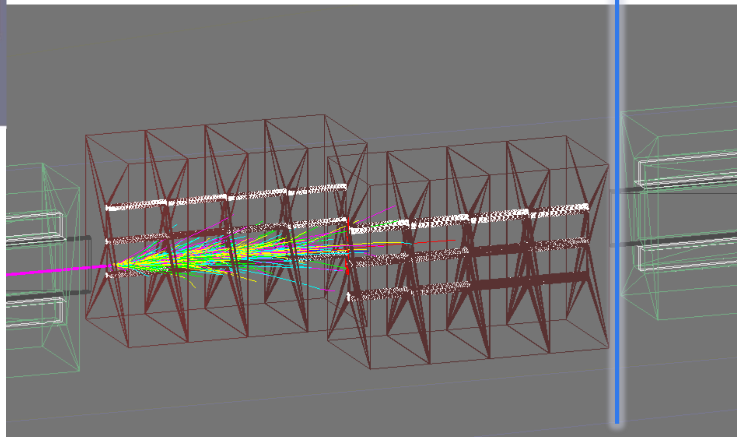


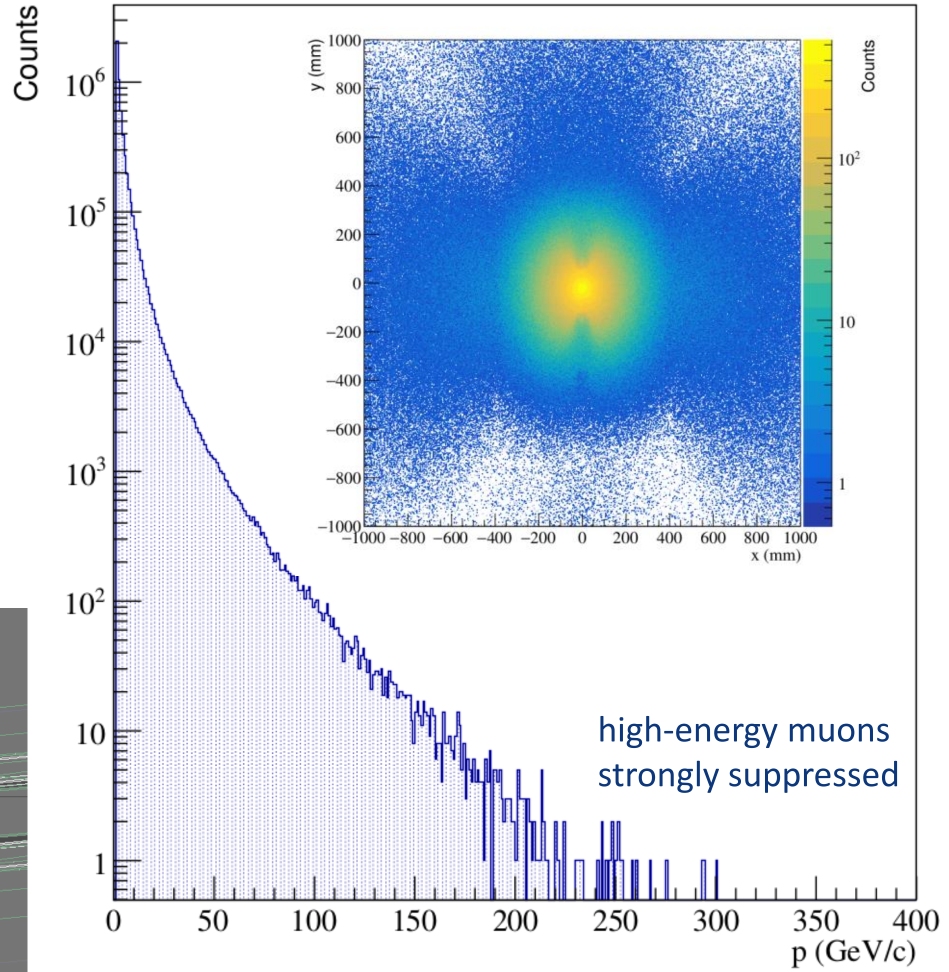
- Simplified model of the detector geometry of NA62

Muon Flux Simulation in Beam Dump Mode

- Changes for Beam dump simulation:
  - Be-target moved out & TAX “closed” to dump protons
- Main sources of muon background
  - Remaining material budget in target region
  - Processes within the TAX



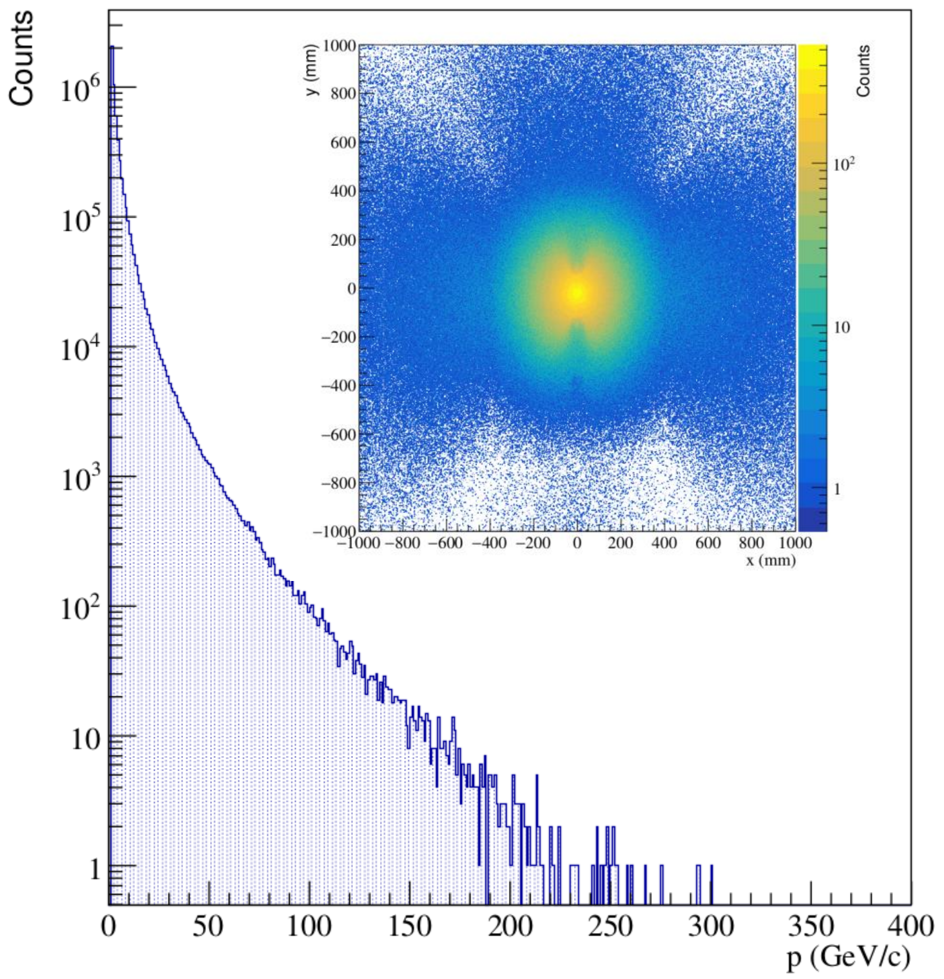




(10^9 incident protons)

Muon Flux Simulation Methods

- Two different simulation methods investigated:
  1. Sampling from particle distribution scored after TAX
     - More statistics without simulating processes in the TAX
     - Limited statistics for high momenta



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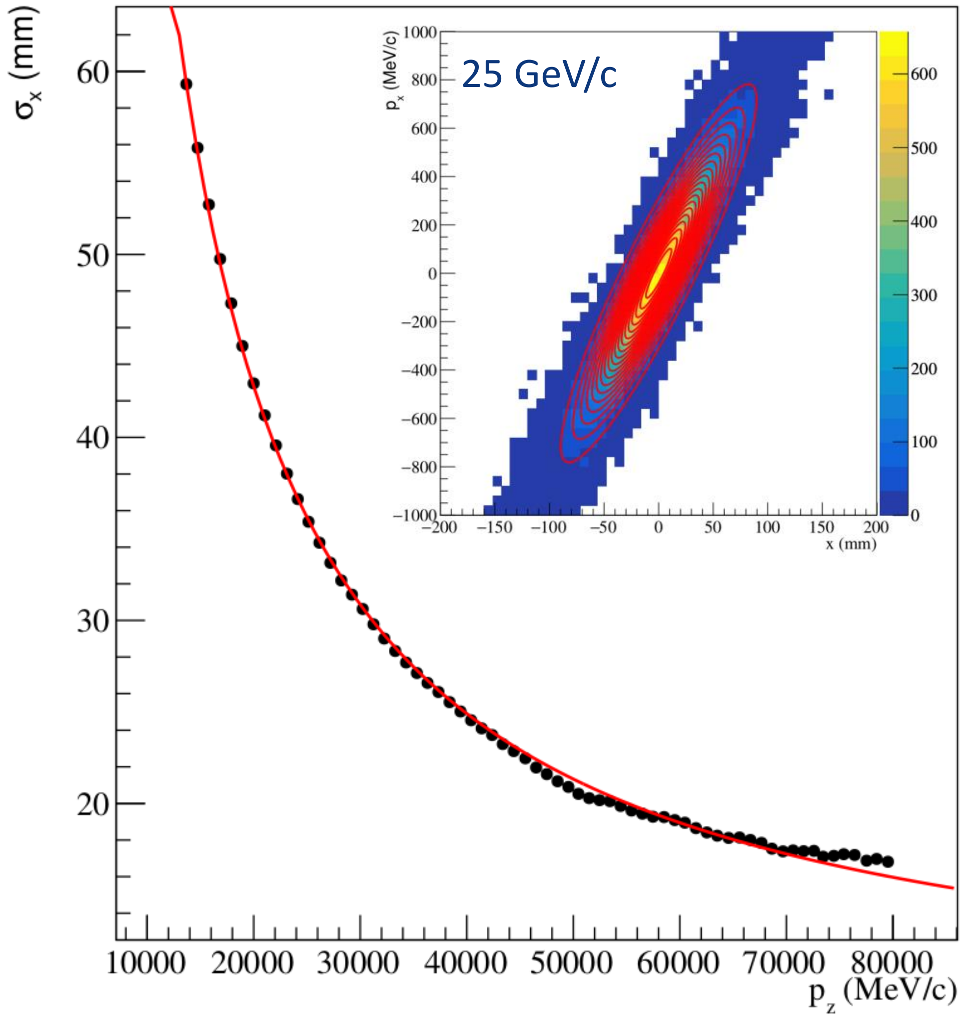

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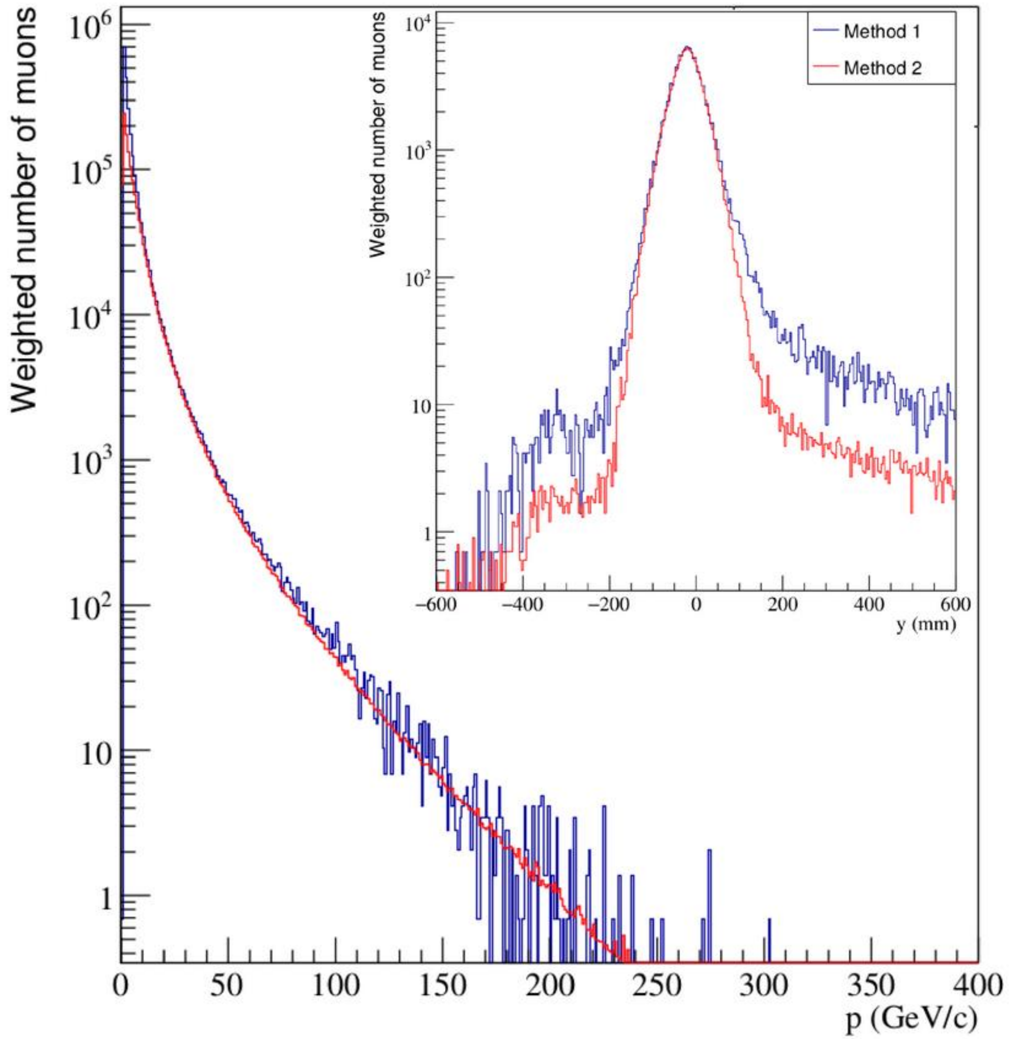
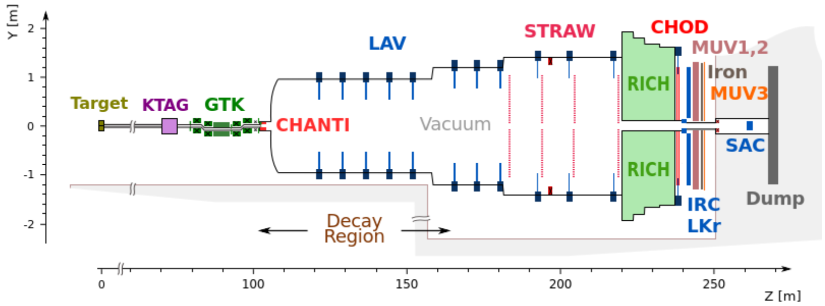
     - Sampling from analytical PDF with individual weights
     - Normalizing to same amount of incident protons

- Comparison of both methods shows very good agreement
- Method 2 allows for:
  - Estimation of high-energy muon distribution
  - Less fluctuations due to normalization only after tracking

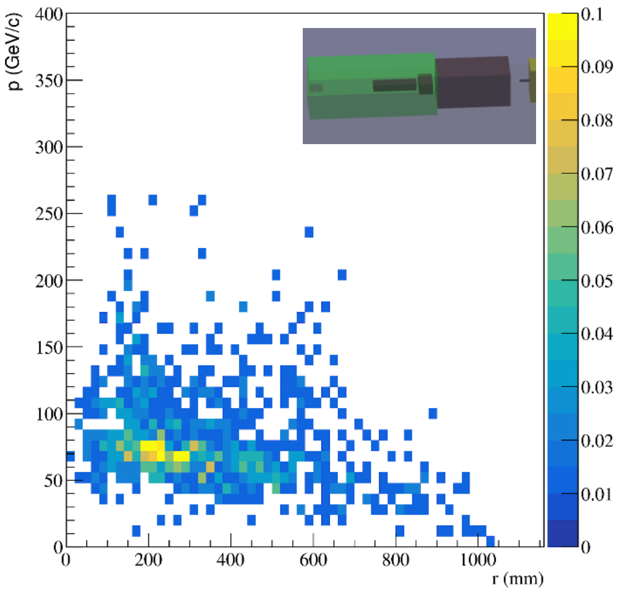


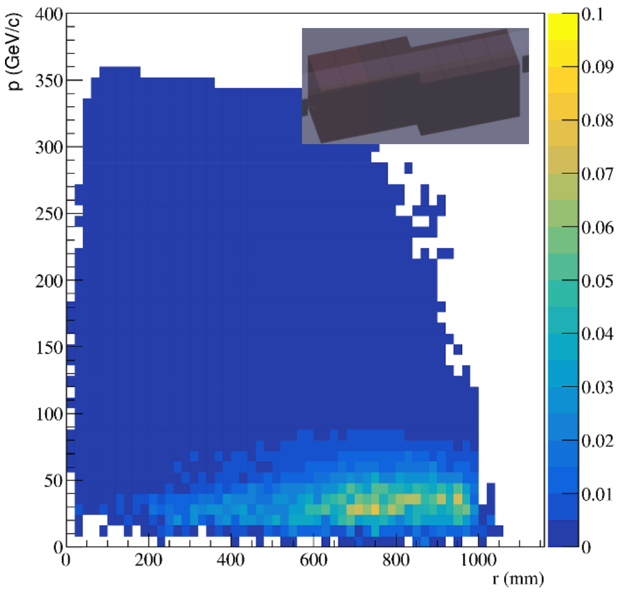
Benchmarking Results in Dump Mode

- Muon simulation compared to data samples recorded in beam dump operation
  - Events triggered by charged particle hit in CHOD
  - Track reconstructed by four straw chamber stations
  - Time-associated hit in muon veto MUV3 requested



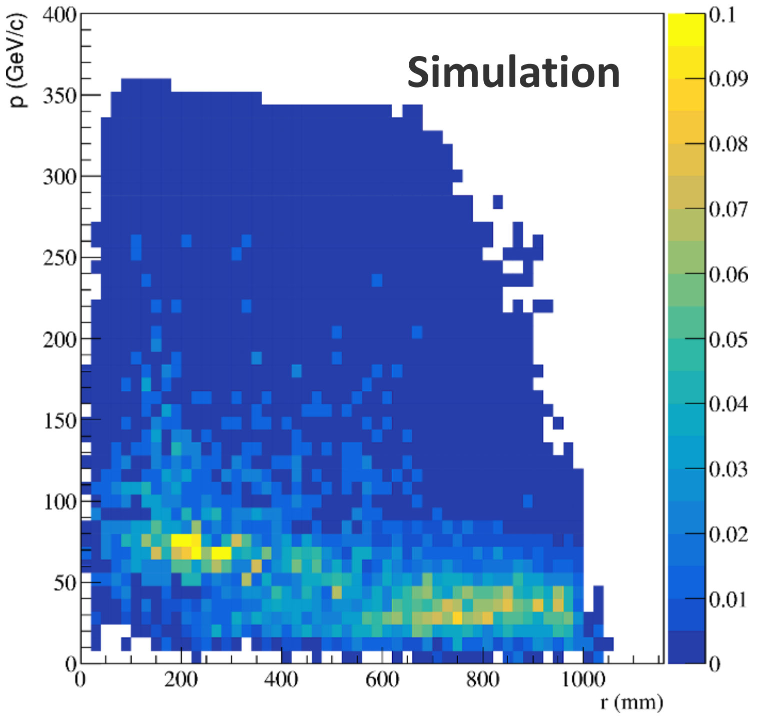
- Simulated muon spectra depend on muon origin:
  - Example: positively charged muons at z=180 m
  - Large component at about 75 GeV/c for muons from upstream decays
  - Lower momenta and larger radii $r = \sqrt{x^2 + y^2}$ for muons produced in TAX

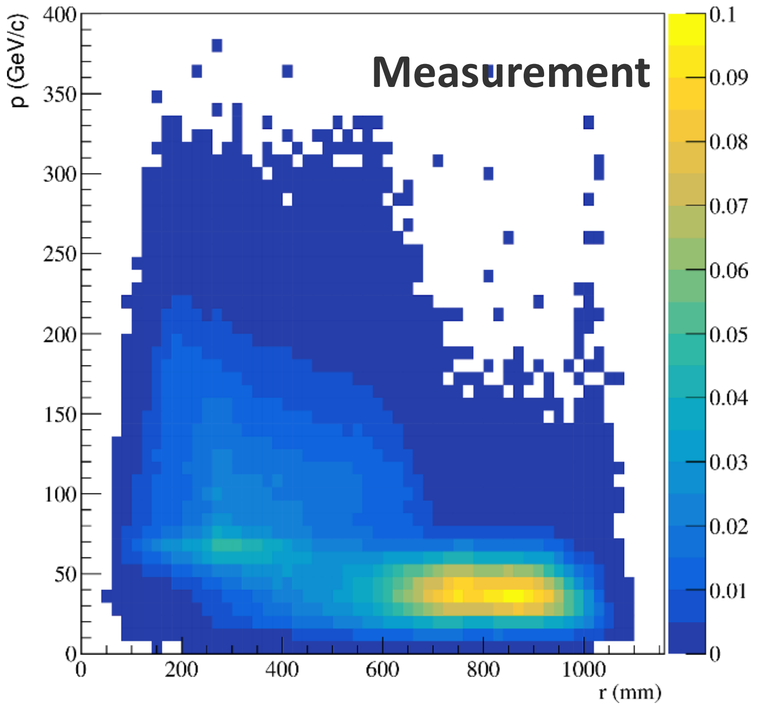




Benchmarking Results in Dump Mode (II)

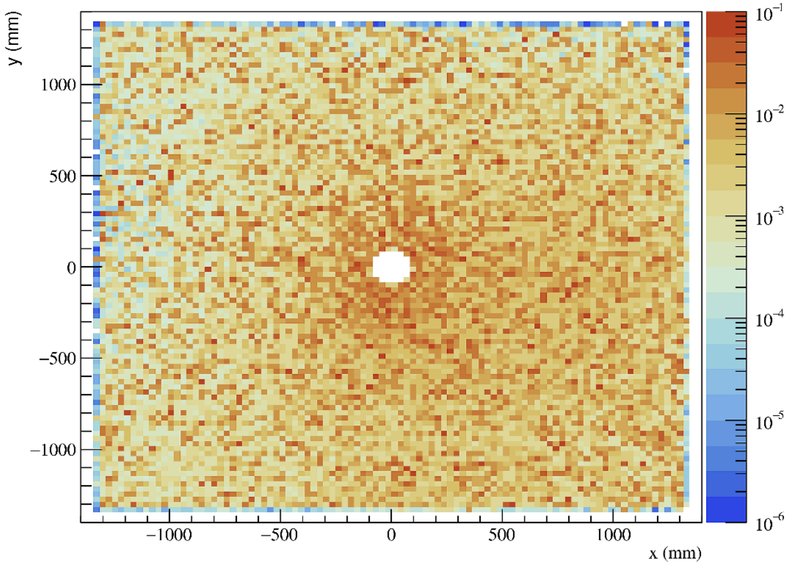
- Good qualitative agreement:
  - Both components observed in data at expected location
- Quantitatively:
  - Measured Data downscaled by factor five
  - Ratio of both simulated contributions different

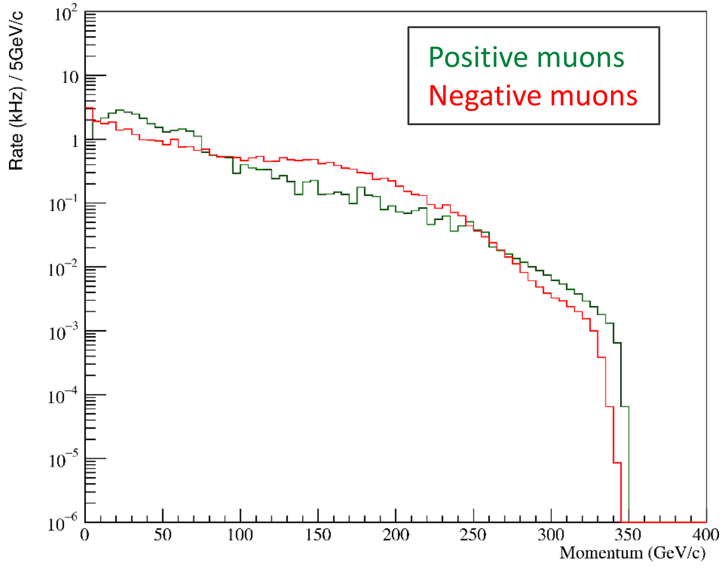




Mitigation of Muon Background

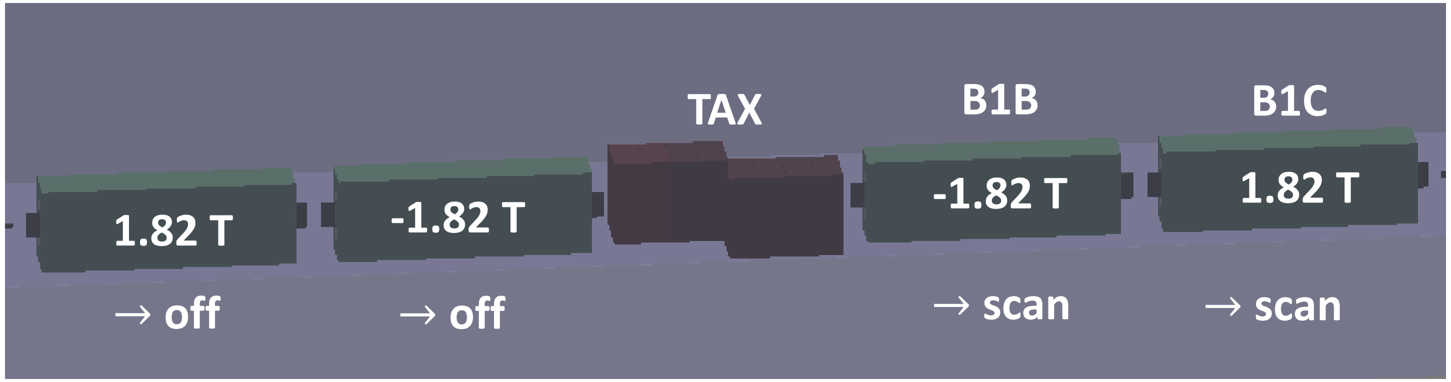
- Simulated muon flux scored in muon veto MUV3 as nominal reference

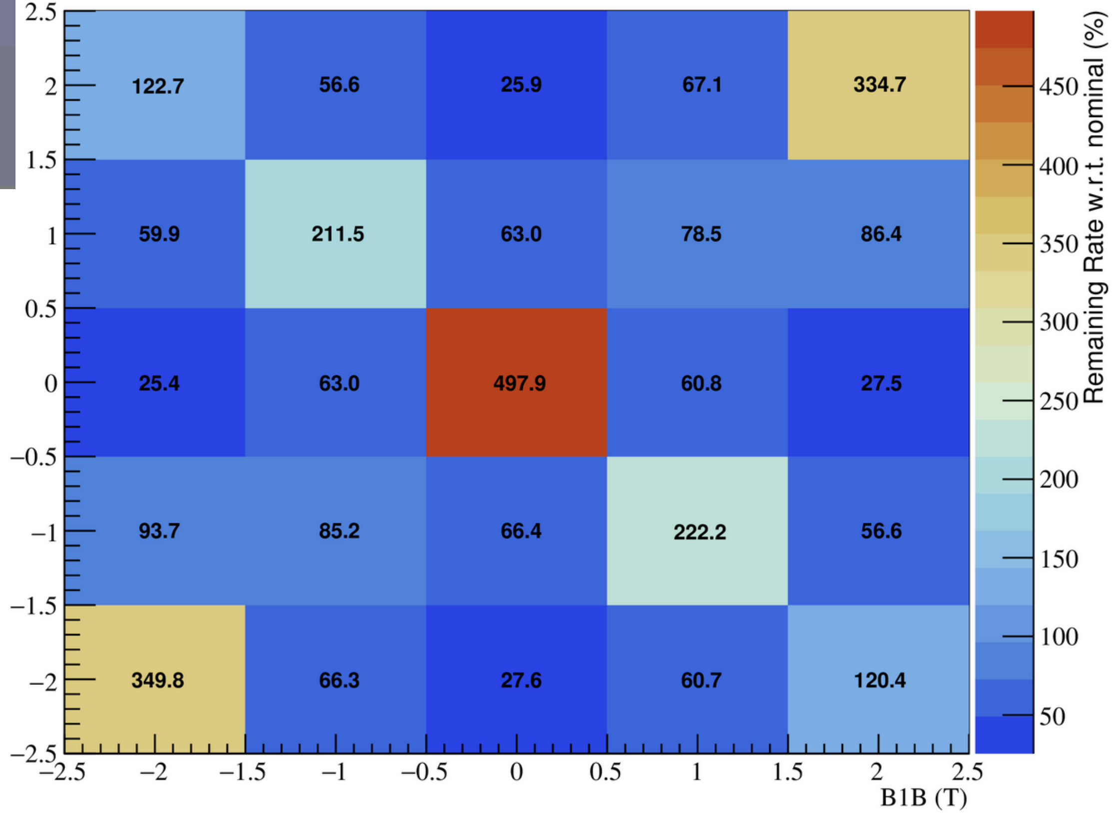




- In nominal setting:
  - Large component close to beam axis
  - Rate difference by 3 orders of magnitude between small and large momenta
- Aim: optimize configuration of magnetic fields to mitigate muons from detector volume

Variation of Magnets of First Achromat

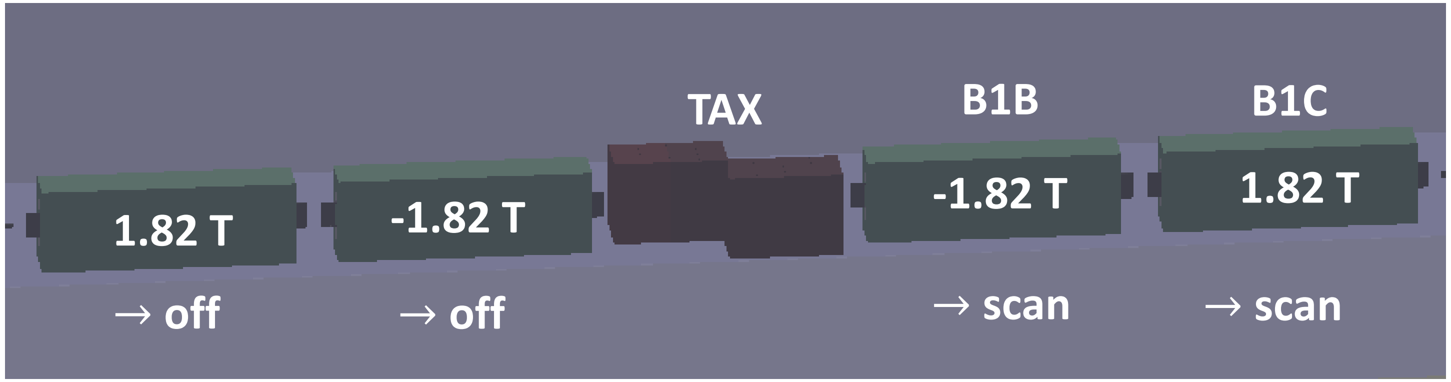




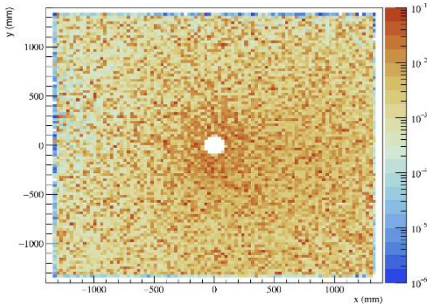
- Beam line optics changes:
  - Optimize quadrupoles in front of TAX for 400 GeV/c
  - Disable quadrupoles behind TAX

- Optimize muon sweeping in vicinity of muon prod.
  - Disable first two bends to avoid vertical displacement of proton beam
  - Scan field strengths of last two bends to find best setting

Variation of Magnets of First Achromat

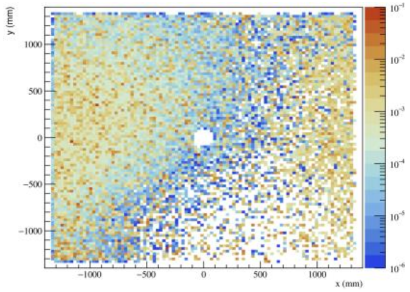


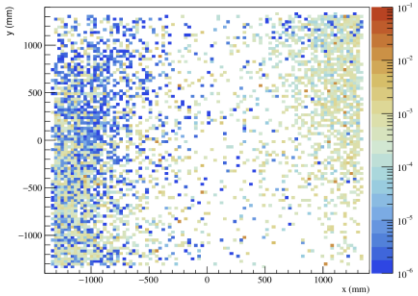
- After further optimization iterations:

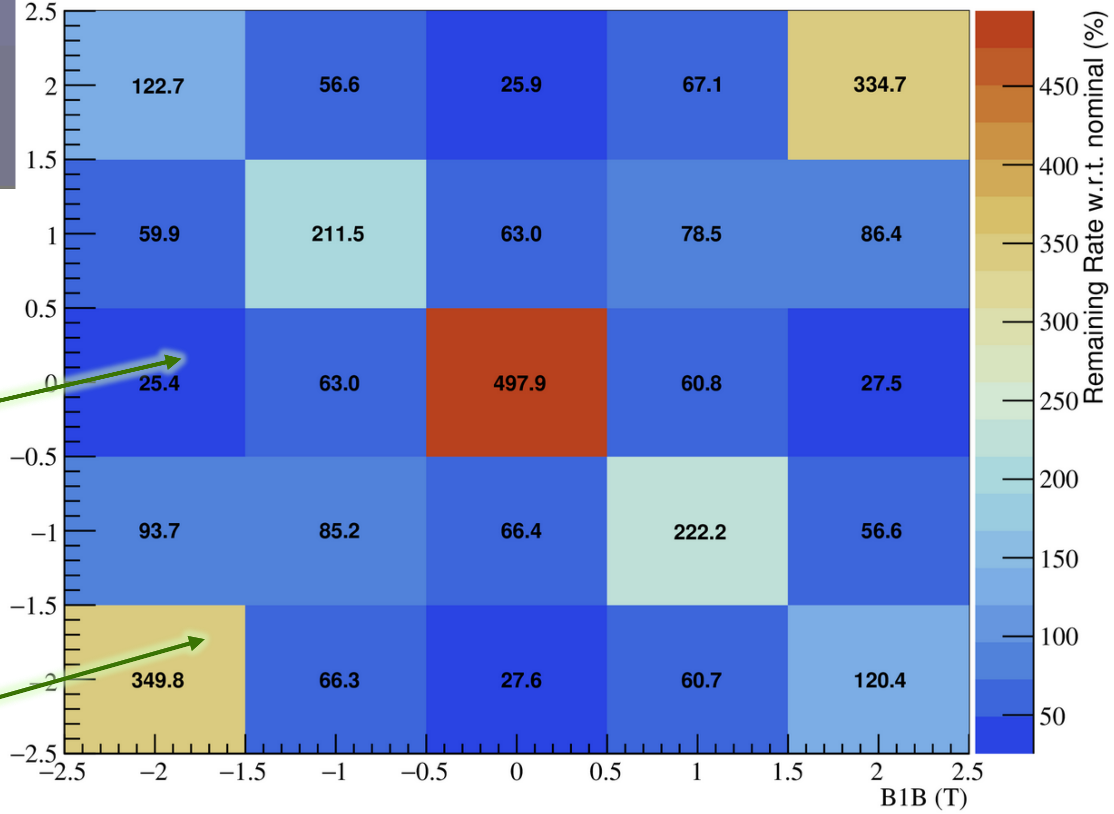


-1.82T, -0.3T
reduction factor:4

-1.82T, -1.82T
p > 15 GeV/c
reduction factor:20







Conclusion

- Successfully implemented a G4beamline model of the K12 beam line at CERN
- Parametrization of muon distribution for estimation of high-momenta muons
  - Significant reduction of computing time achieved, enabling benchmarking and optimization studies
- Qualitative agreement of muon distributions between measurement and simulation observed
  - Quantitative discrepancies under investigation
- First studies on muon background mitigation in NA62 beam dump mode performed
  - Reduction by factor four at MUV3 detector observed in simulations

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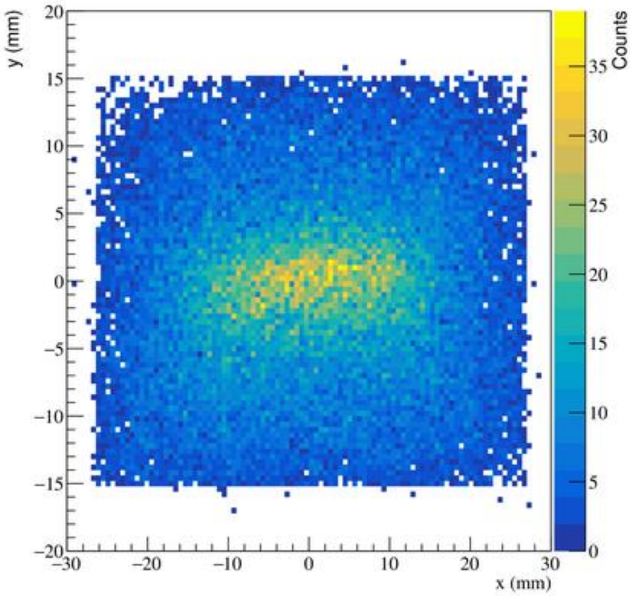
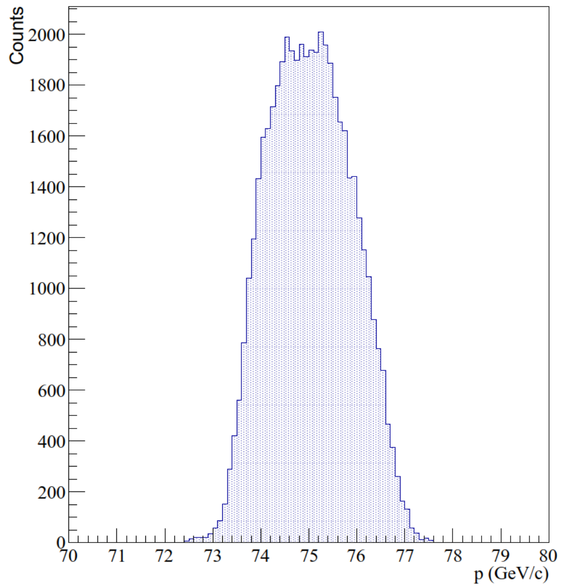
Benchmarking of Nominal Configuration

- Simulated beam scored before fiducial volume of NA62 (≈102 m)

- Beam spot size and momentum spread simila to NA62 Technical Design Report
  - Centered around 75 GeV/c
  - Momentum Spread: ~1%

- Beam rates:
  - Pions and kaons in good agreement
  - Slight excess of protons observed





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