The high-intensity muon beam line (HiMB) project at PSI

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for the HiMB project

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Motivation

- PSI home to highest intensity DC μ^+ beam: $5 \times 10^8\ \mu^+/s$
- Next generation cLFV experiments require higher muon rates
- Provide new opportunities for µSR experiments
- Maintain PSI leadership in high intensity muon beams and its expertise in low-energy precision physics

J-PARC $\rightarrow 10^{10}\ \mu^-/s$

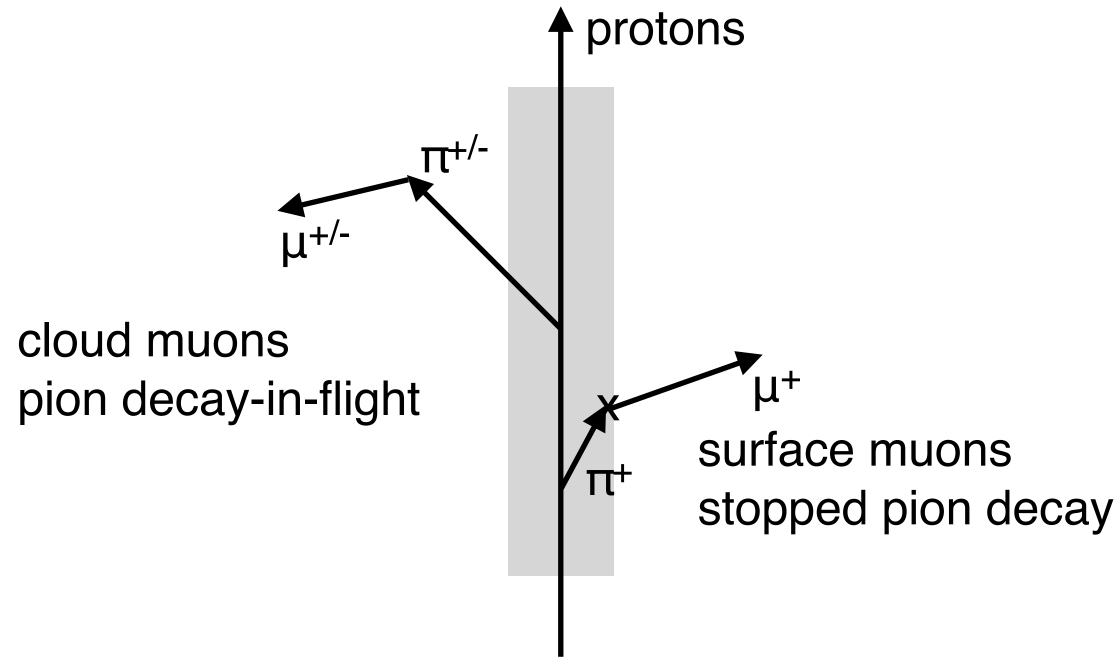
COMET: $R_{\mu e} = \mathcal{O}(10^{-17})$

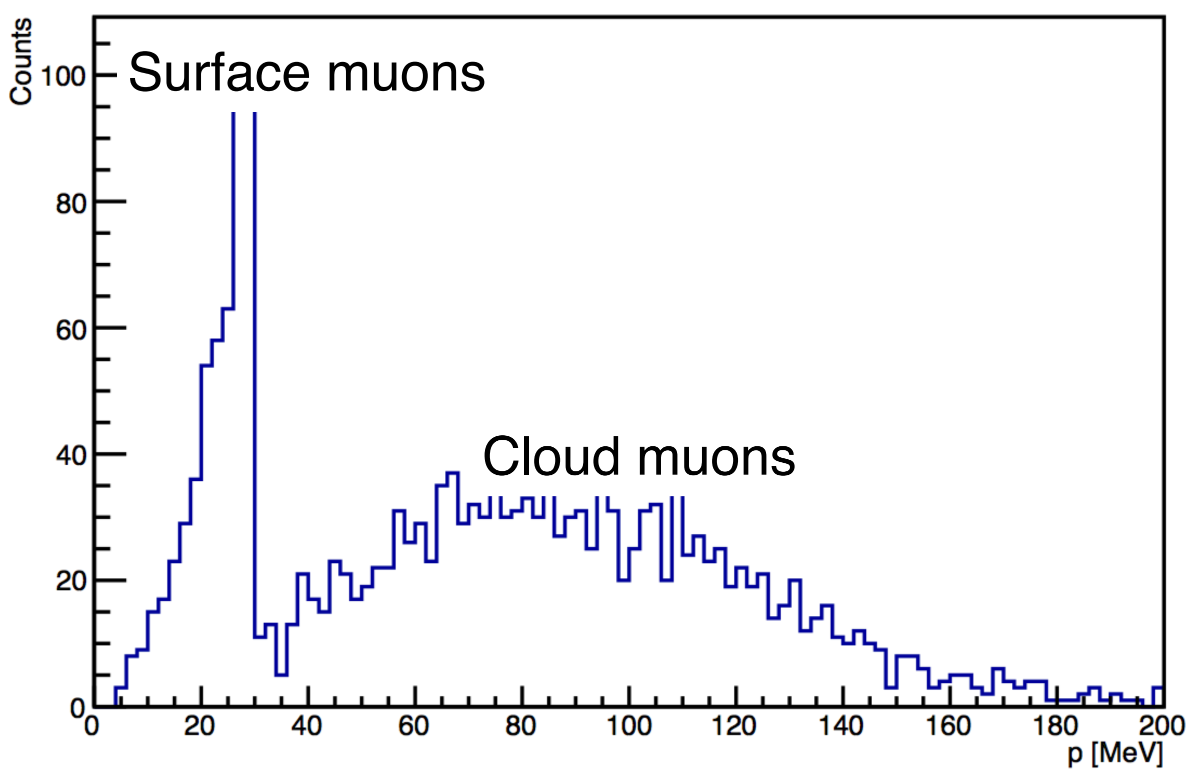
Fermilab $\rightarrow 5 \times 10^{10}\ \mu^-/s$

Mu2e: $R_{\mu e} = \mathcal{O}(10^{-17})$

Surface muons

- Low-energy muon beam lines typically tuned to surface-μ^+ at ~ 28 MeV/c
- Contribution from cloud muons at similar momentum about 100x smaller
- Negative muons only available as cloud muons

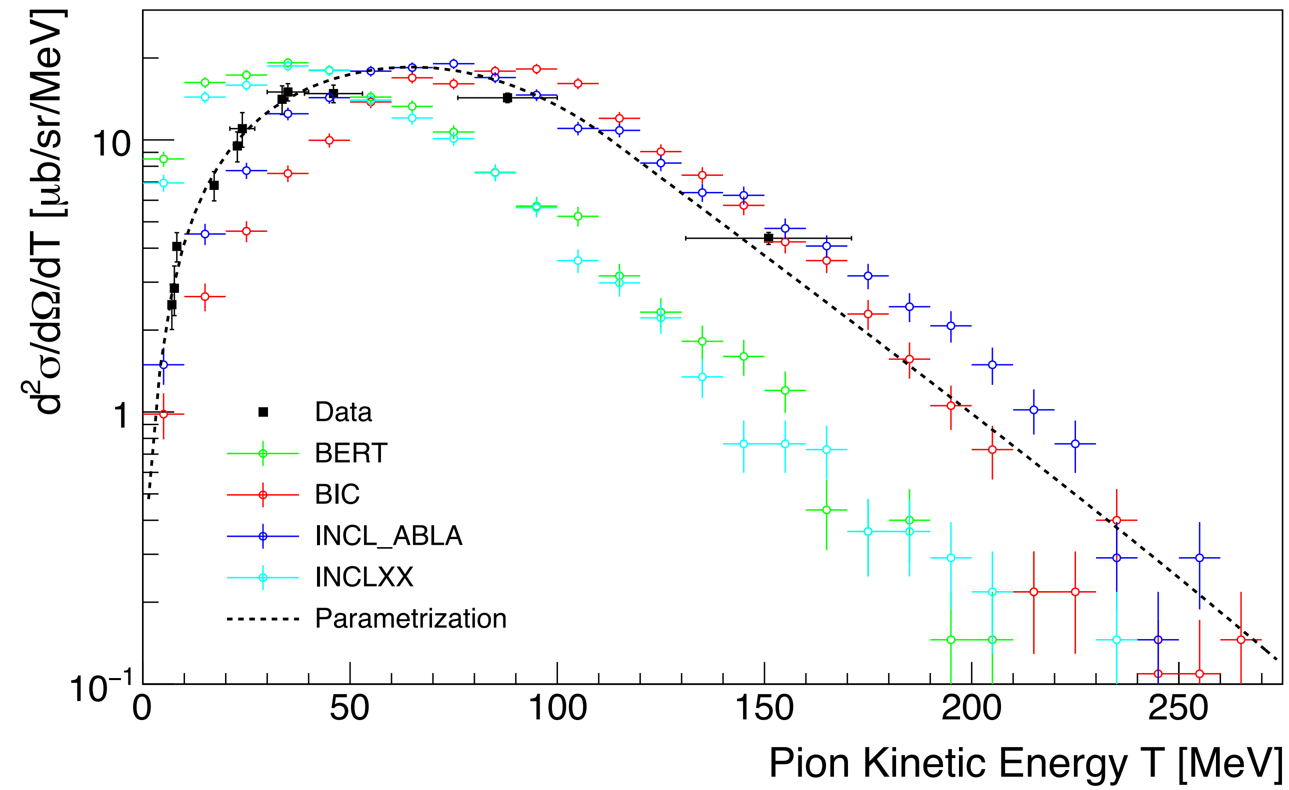


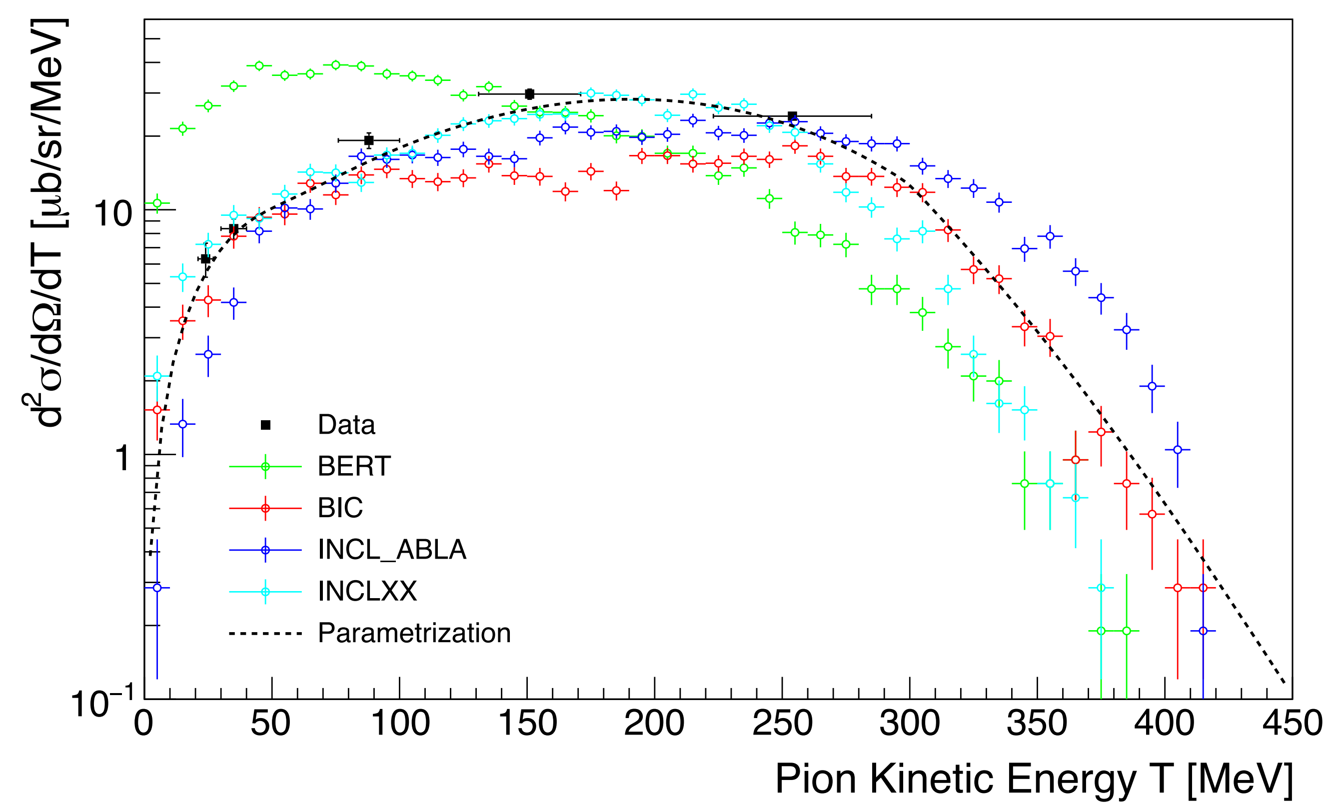


Simulation

- Implemented our own pion production cross sections into Geant4/G4beamline based on measured data and two available parametrizations
- Valid for all pion energies, proton energies < 1000 MeV, all angles and all materials
- Implemented “splitting” of pion production and muon decay to speed up simulation

⇒ Reliable results at the 10% level

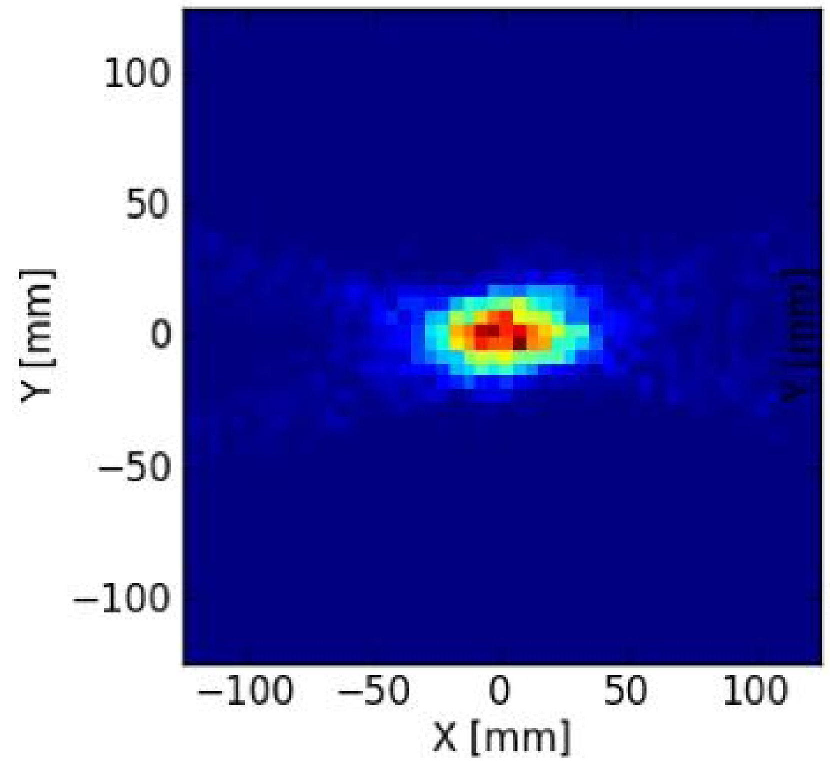


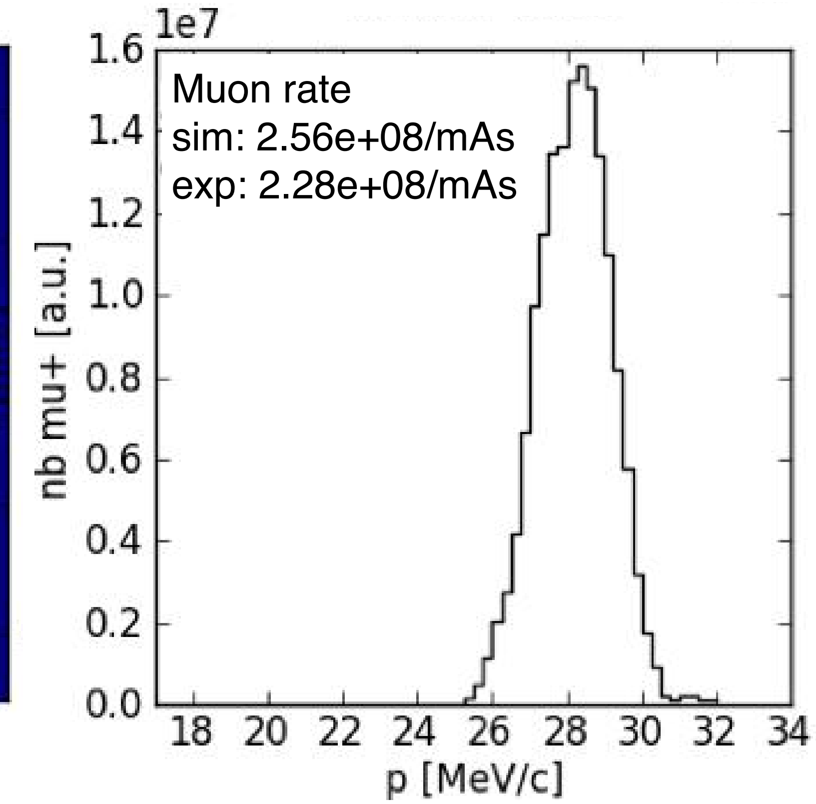


R. L. Burman and E. S. Smith, Los Alamos Tech. Report LA-11502-MS (1989)
R. Frosch, J. Löffler, and C. WIgger, PSI Tech. Report TM-11-92-01 (1992)
F. Berg et al., Phys. Rev. Accel. Beams **19**, 024701 (2016)

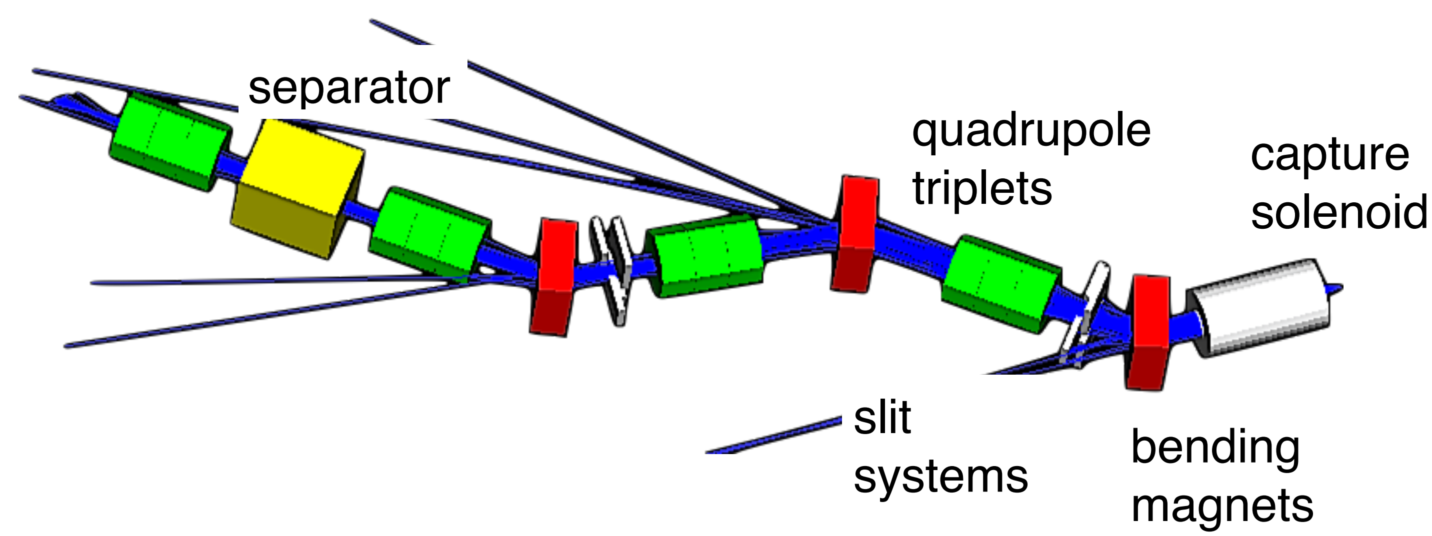
Simulation Validation

- Full simulation of µE4 beamline starting from proton beam
- Detailed fieldmaps available for all elements





⇨ Excellent agreement between simulation and measurements



Floorplan PSI

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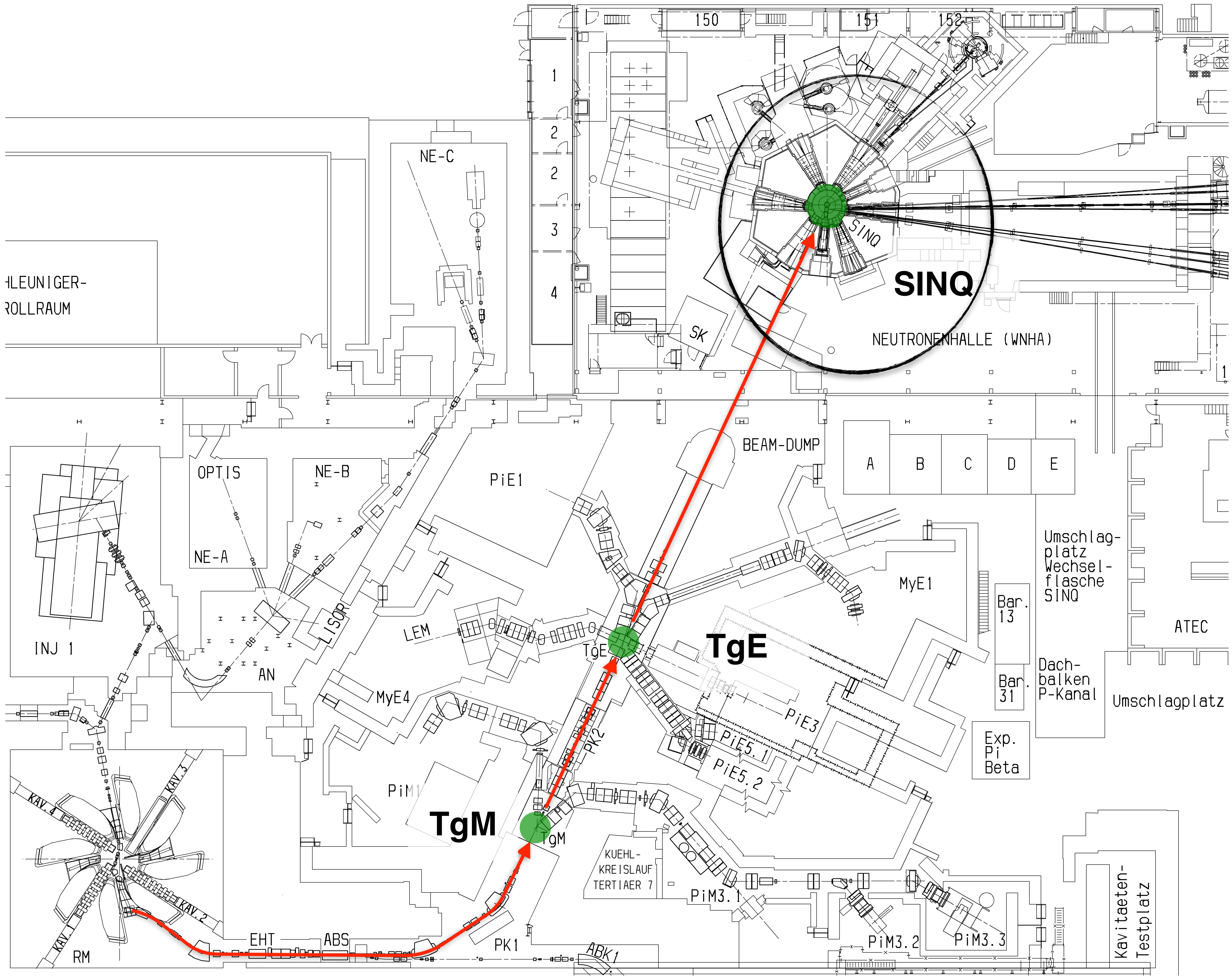
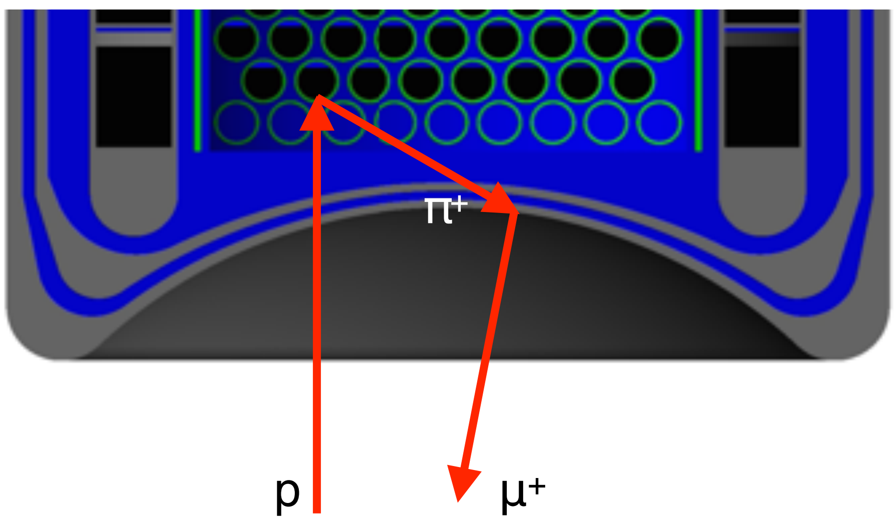
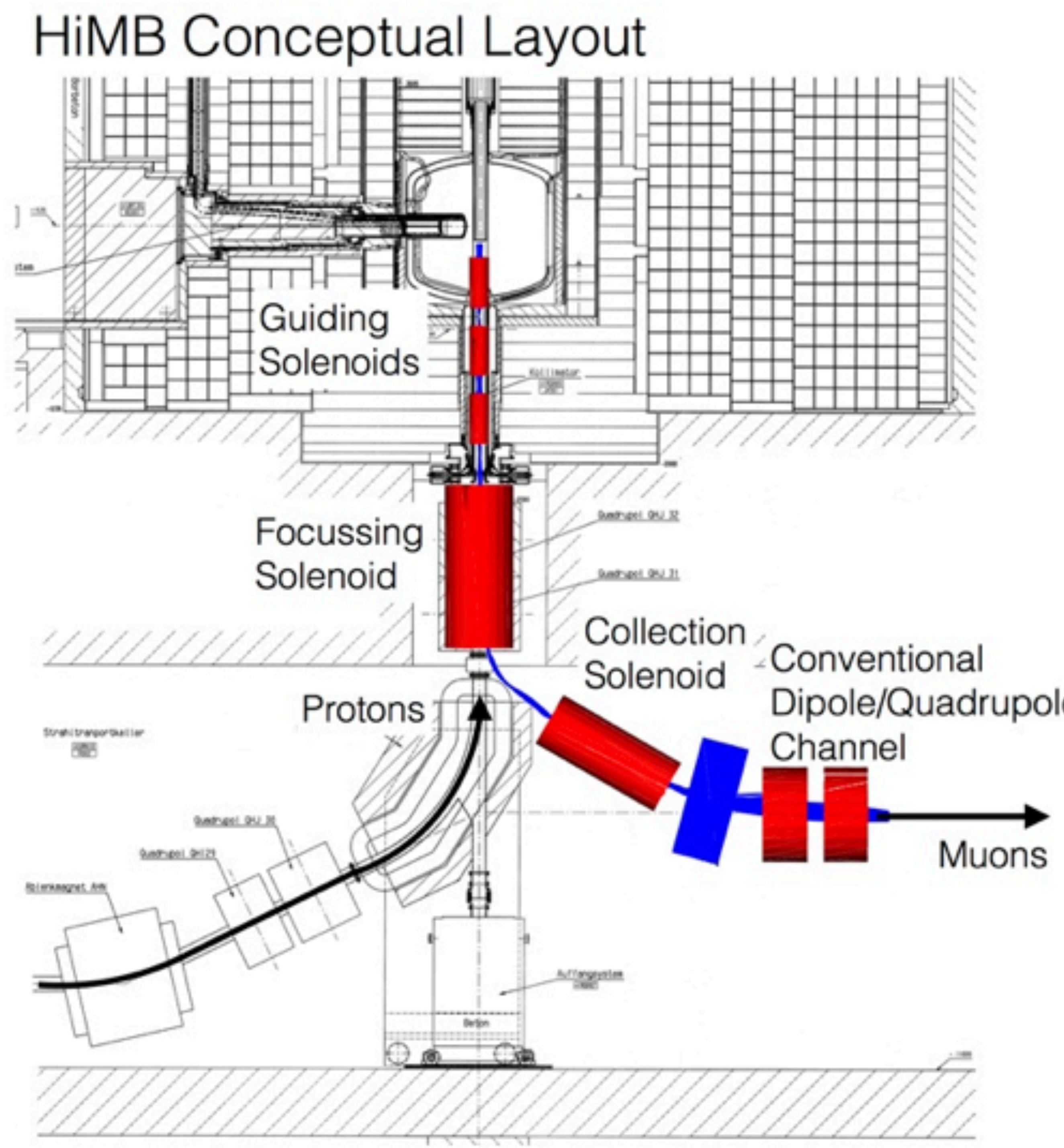
PSI



Initial HiMB Concept: HiMB@SINQ

SINQ spallation target



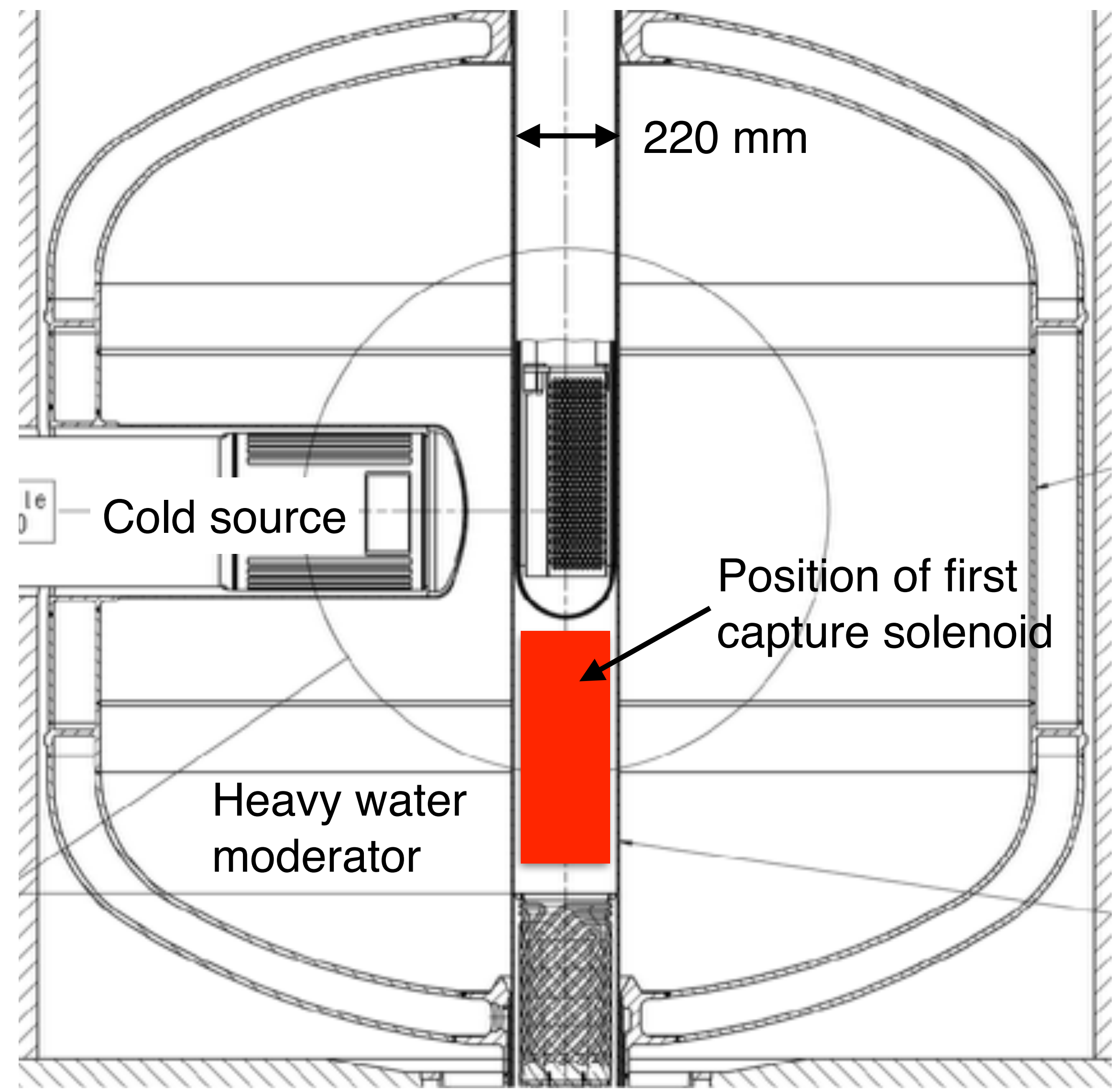


- Extract surface muons from safety window of SINQ spallation target
- Profit from stopping of full beam

Initial HiMB Concept: HiMB@SINQ

- Source simulation (below safety window):
  9×10^{10} surface-μ^+/s @ 1.7 mA I_p
- First capture solenoid needs to be very close, radiation hard, high-field, large aperture, …
- After several iterations with with a variety of capture elements:

⇨ Severe space constraints restrict the capture of a sufficient number of muons for a high-intensity beam!



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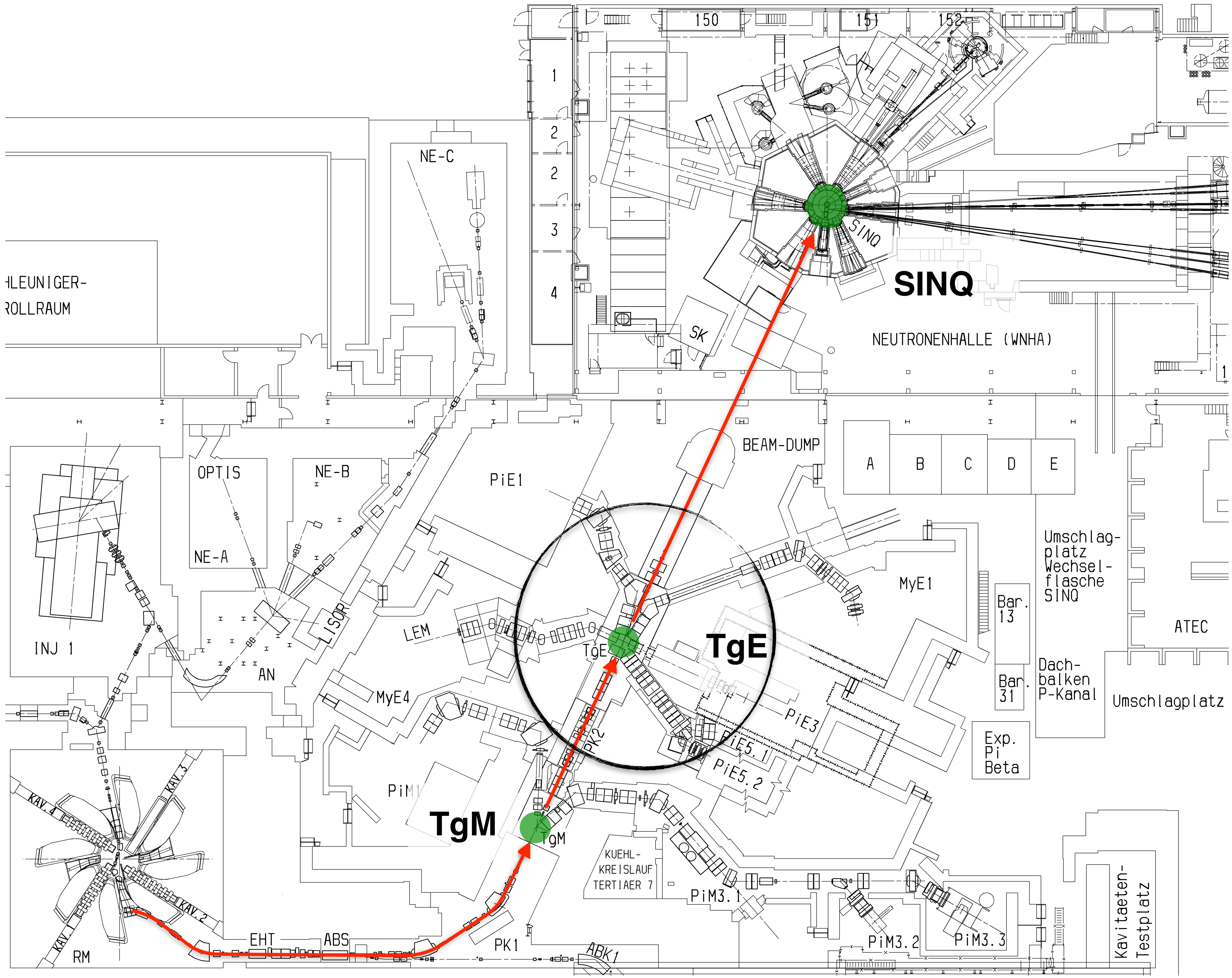
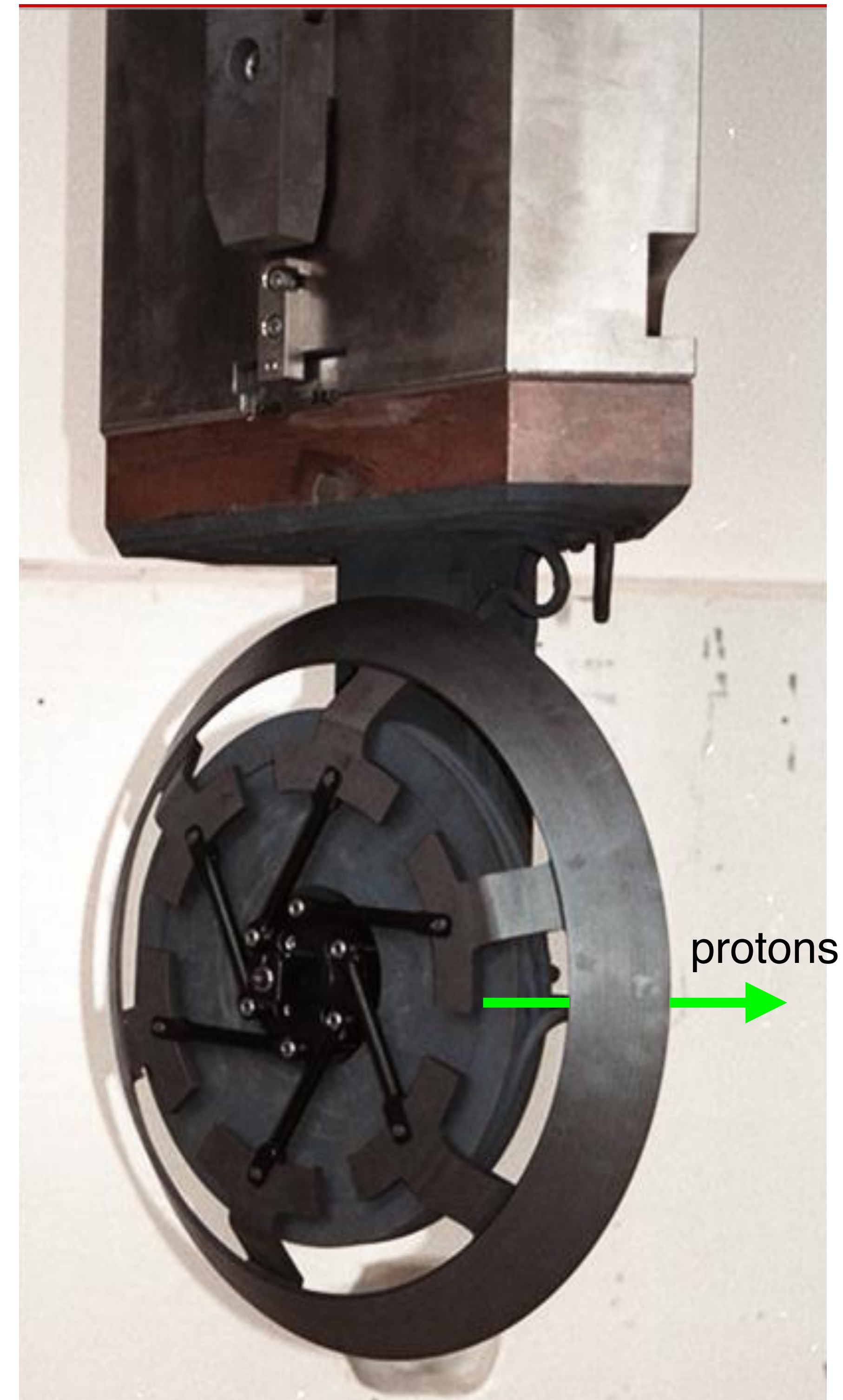


Target wheel of TgE station

- 40 mm polycrystalline graphite
- ~40 kW power deposition
- Temperature 1700 K
- Radiation cooled @ 1 turn/s
- Beam loss 12% (+18% from scattering)



Performance of Standard Targets

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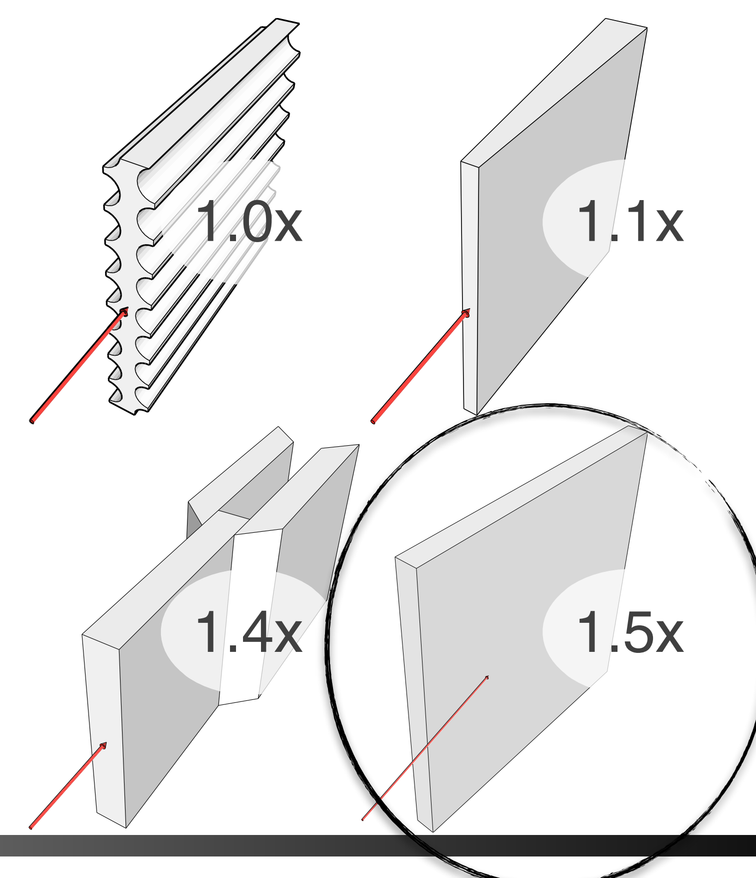
- Realized that standard targets are as efficient in generating 28 MeV/c surface muons as spallation targets

Surface muon rates in μ+/s for TgE geometry of different lengths

Length	Upstream	Downstream	Side
10	1.4×10^{10}	9.0×10^{9}	1.8×10^{10}
20	1.6×10^{10}	1.2×10^{10}	5.1×10^{10}
30	1.9×10^{10}	1.1×10^{10}	8.5×10^{10}
40	1.8×10^{10}	1.1×10^{10}	1.2×10^{11}
60	1.8×10^{10}	1.2×10^{10}	2.1×10^{11}

- After extensive target simulations: Slanted targets are even better!



Alternate Materials

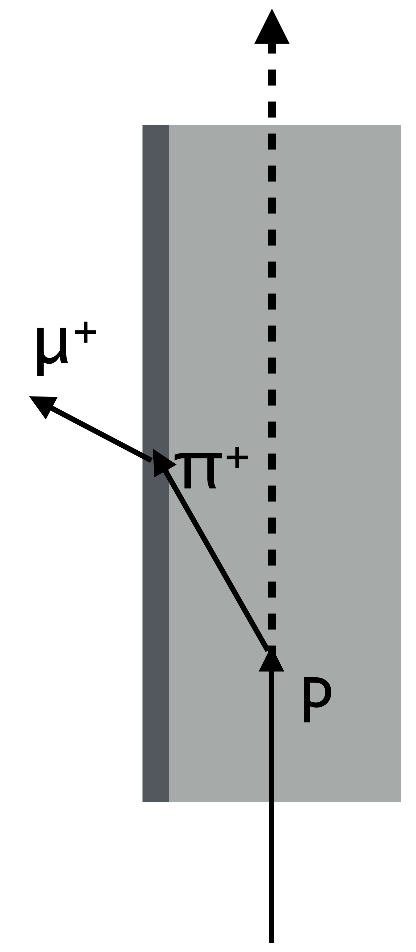
- Search for high pion yield materials → higher muon yield

$$relative\ \mu^+ yield \ \propto\ \pi^+ stop\ density \cdot \mu^+ Range \cdot length$$

$$\propto n \cdot \sigma_{\pi^+} \cdot SP_{\pi^+} \cdot \frac{1}{SP_{\mu^+}} \cdot \frac{\rho_C (6/12)_C}{\rho_x (Z/A)_x}$$

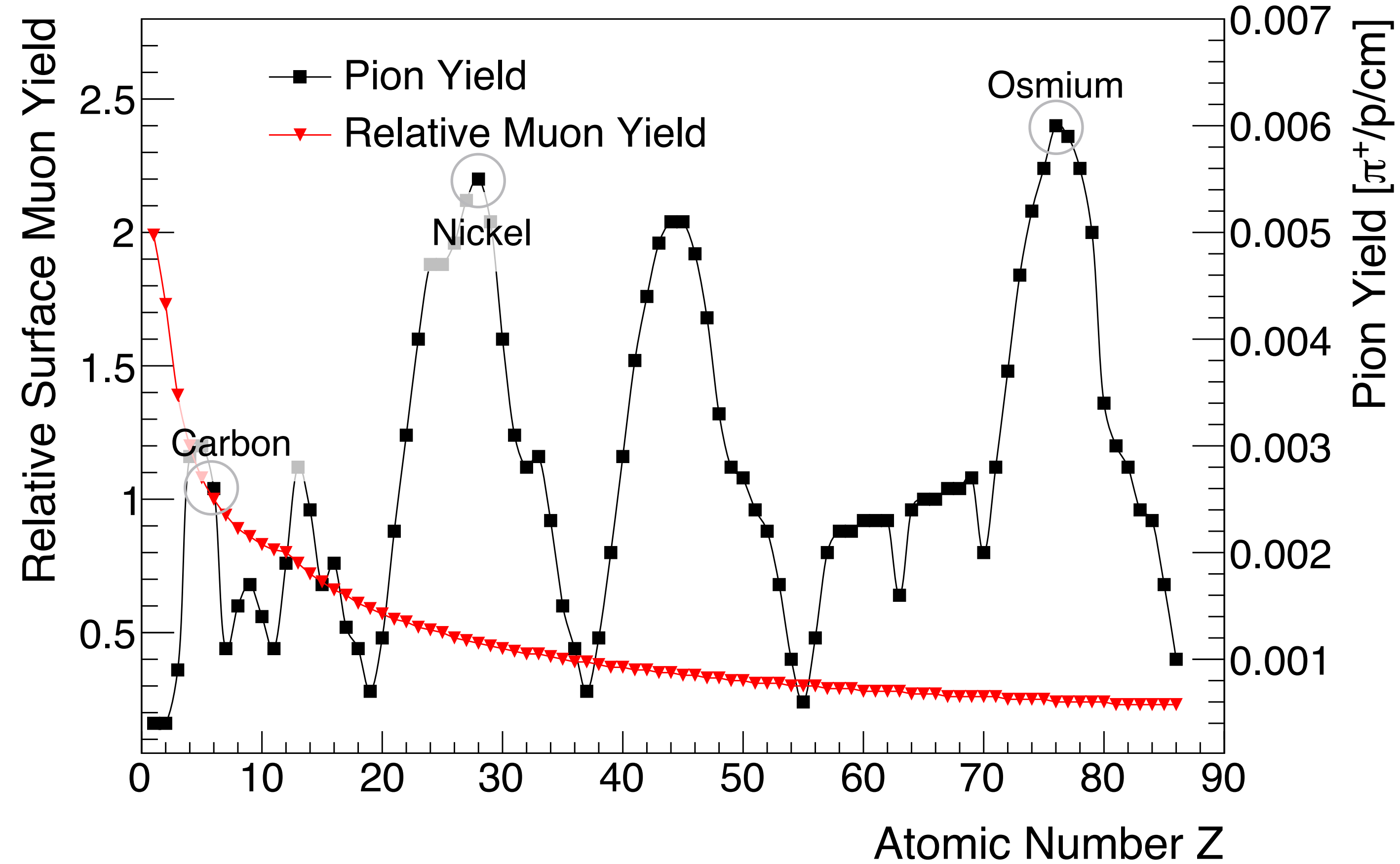
$$\propto Z^{1/3} \cdot Z \cdot \frac{1}{Z} \cdot \frac{1}{Z}$$

$$\propto \frac{1}{Z^{2/3}}$$



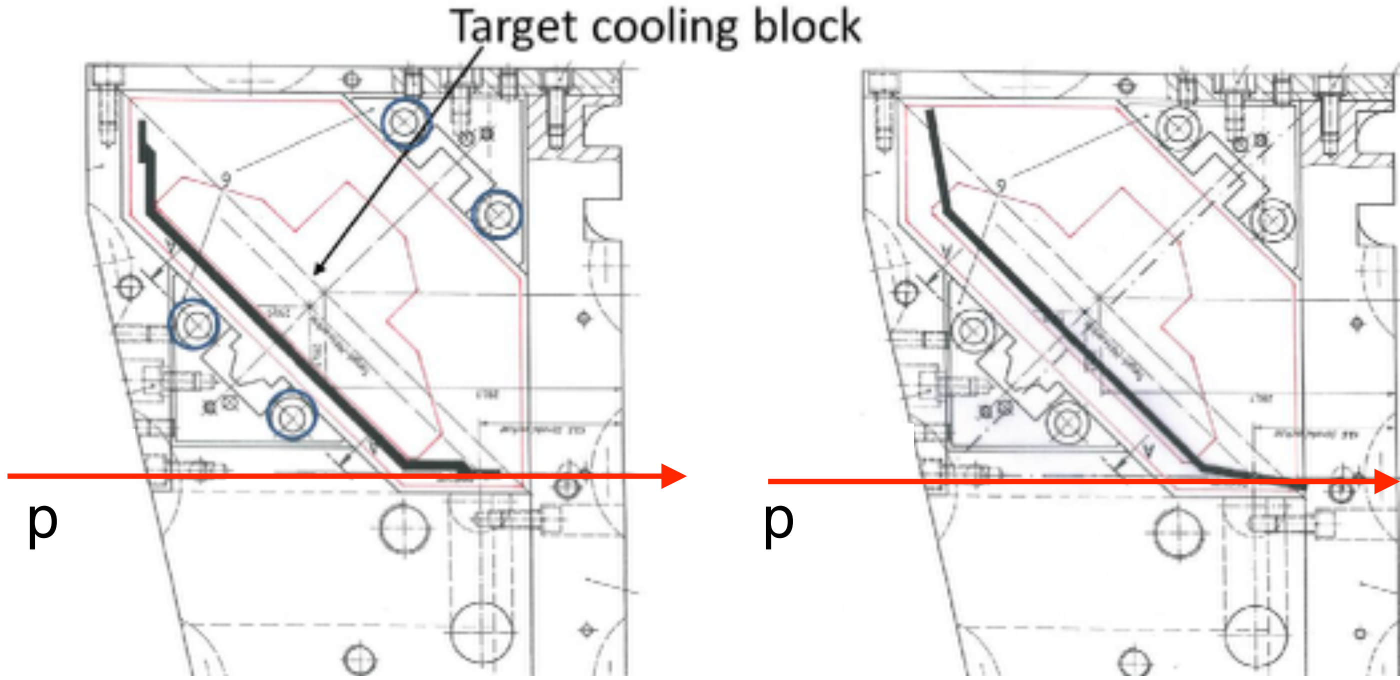
Alternate Materials

- Several materials have pion yields > 2x Carbon
- Relative muon yield favours low-Z materials, but difficult to construct as a target
- B_4C and Be_2C show 10-15% gain

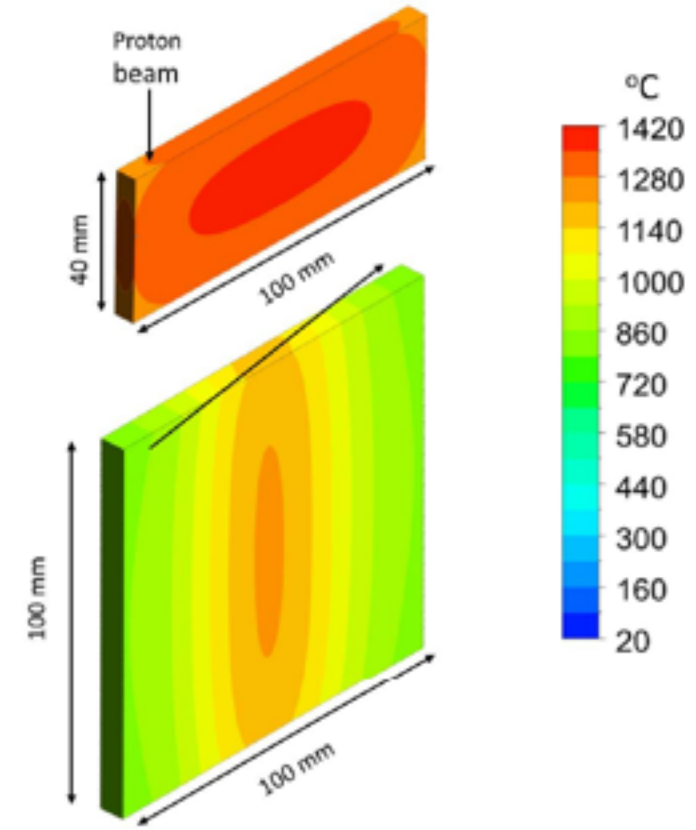


Prototype Slanted TgE

- Slanted graphite target that fits into the TgE vacuum chamber under mechanical design

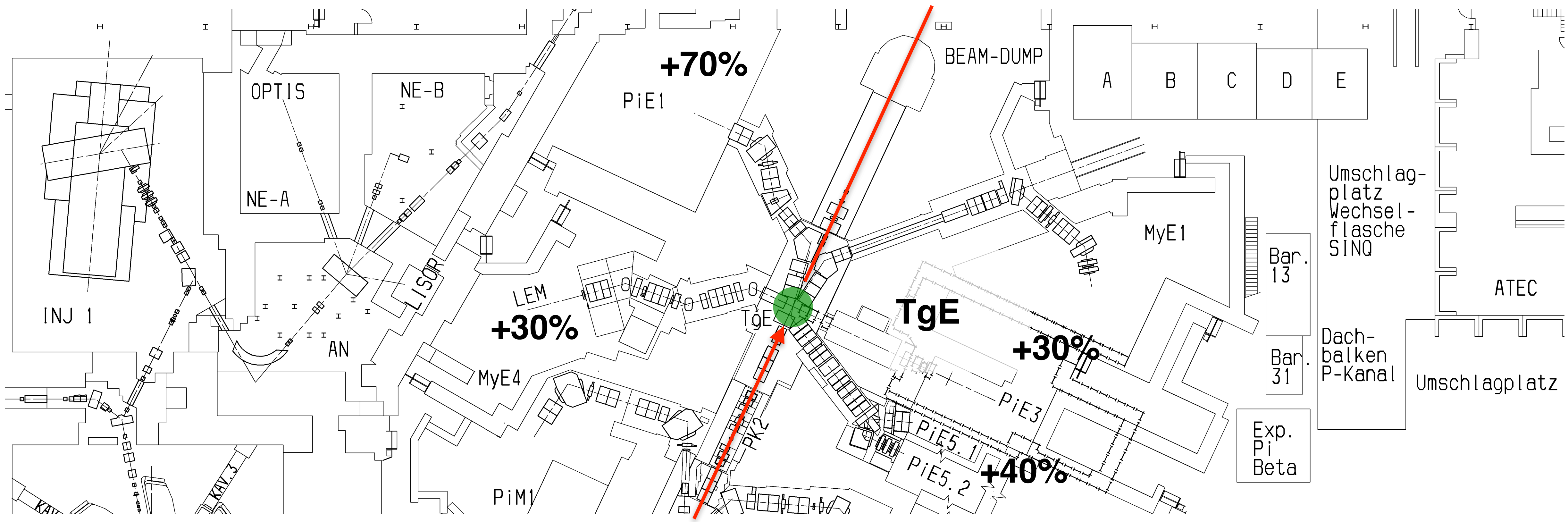


- First thermal simulations of the slanted target started
- Will need to estimate amount of possible deformations as there are tight mechanical constraints



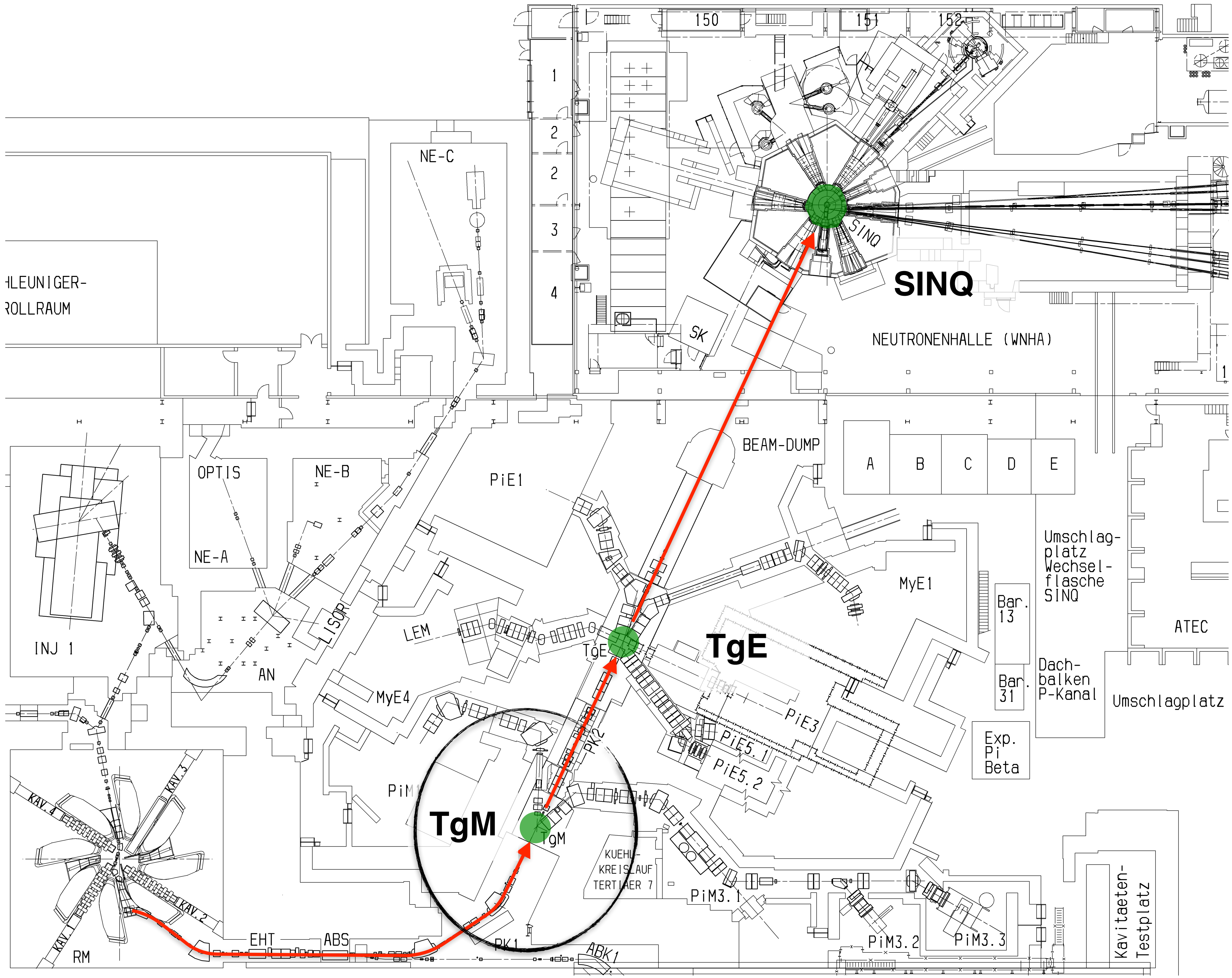
- Aiming at test end of 2018

Prototype Slanted TgE

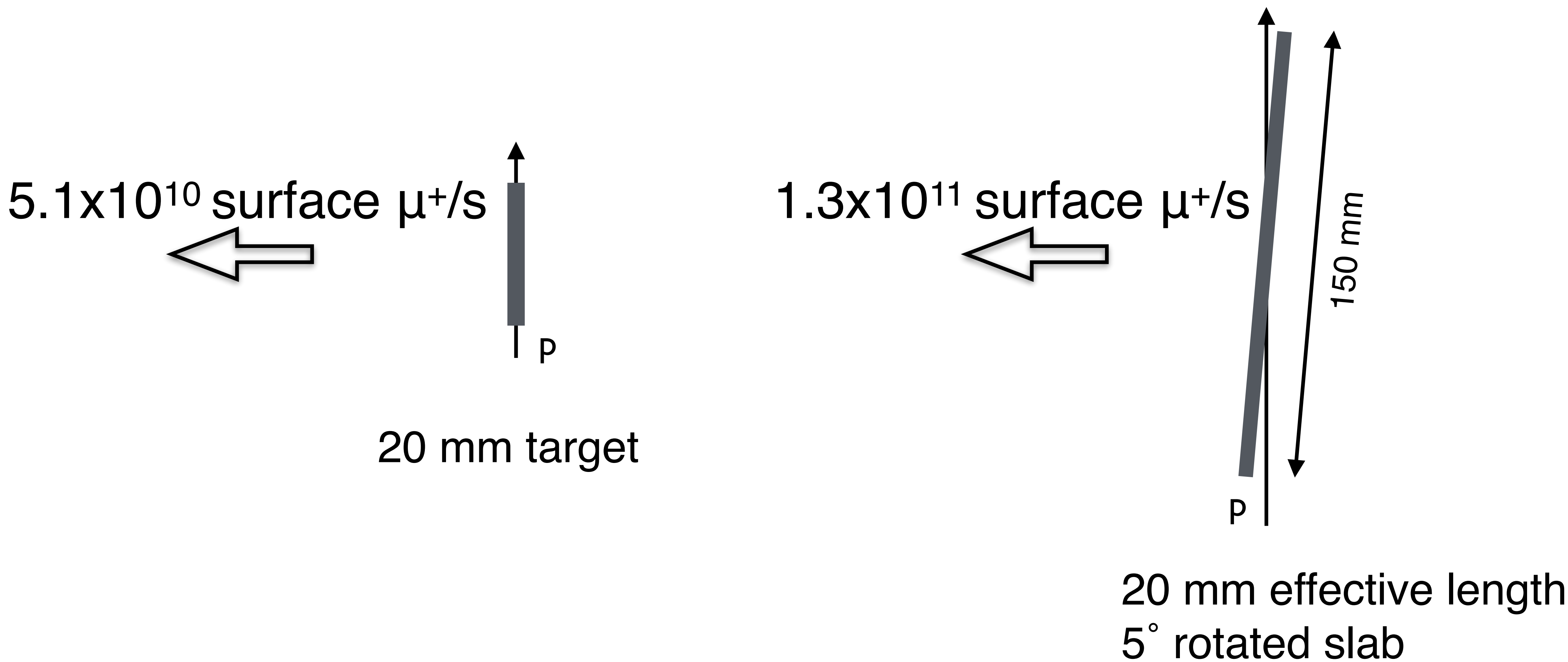


- Expected gains in surface muon rate at the acceptance points of the different beam lines
- Slanted target at 10 degrees, slant length of 100 mm, effective length in beam direction of 40 mm

Floorplan PSI

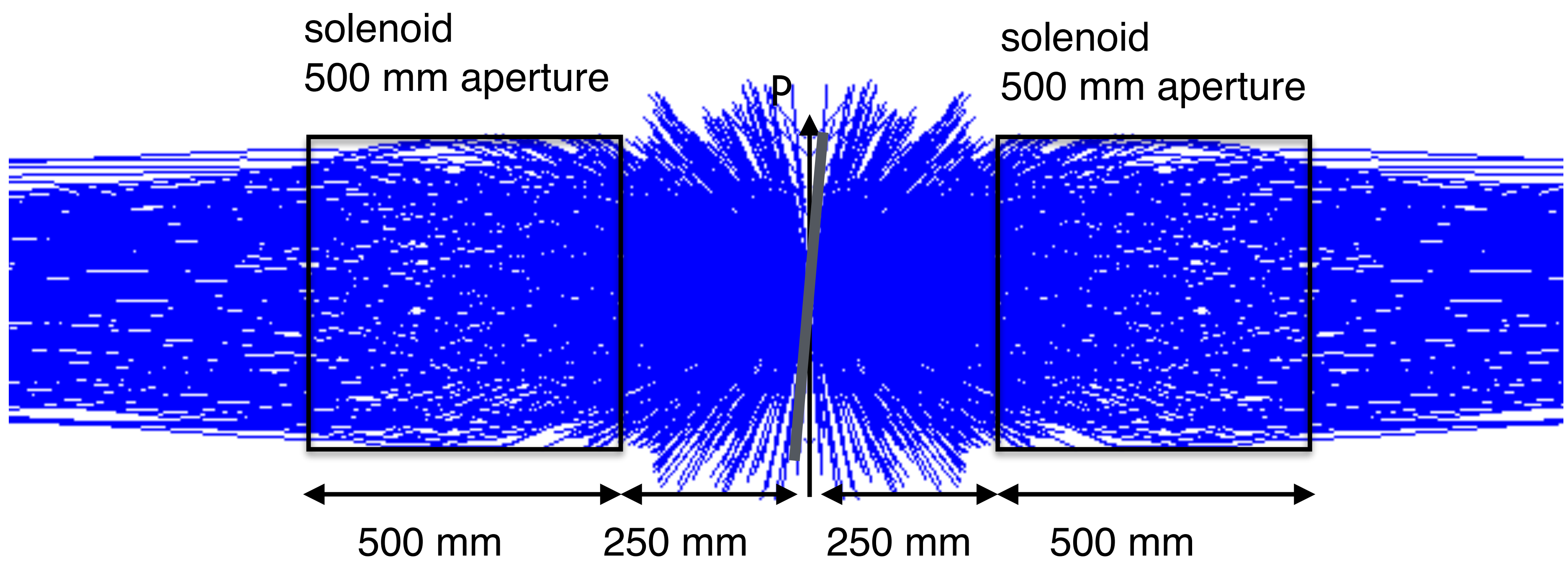


Target Geometry for new TgM*



- Change current 5 mm TgM for 20 mm TgM*
- 20 mm rotated slab target as efficient as Target E

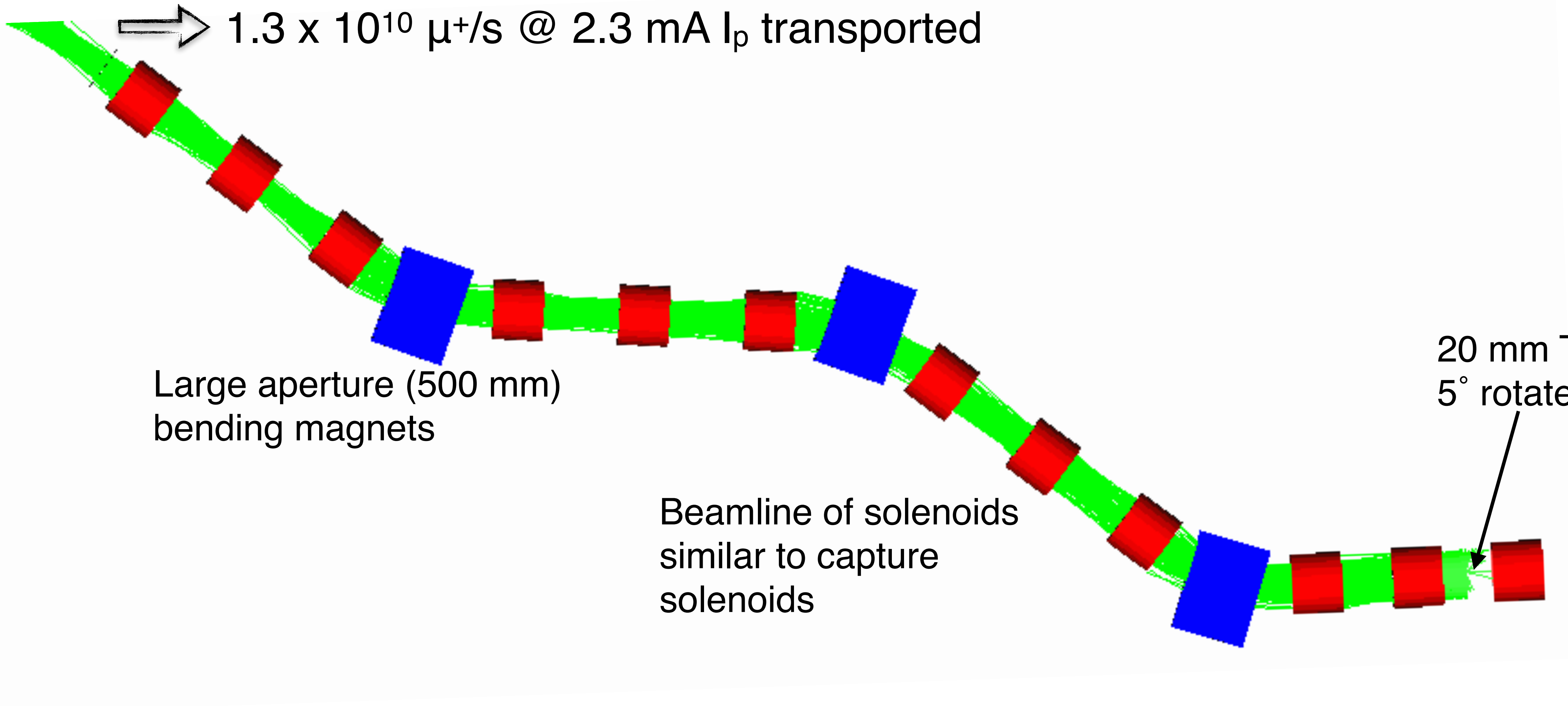
Split Capture Solenoids



- Two normal-conducting, radiation-hard solenoids close to target to capture surface muons

- Central field of solenoids ~0.35 T
- Field at target ~0.1 T

Solenoid Beamline: HiMB@EH



- First version of beam optics showing that large number of muons can be transported.
- Almost parallel beam, no focus, no separator, …
- Final beam optics under development

Solenoid Beamline: HiMB@EH

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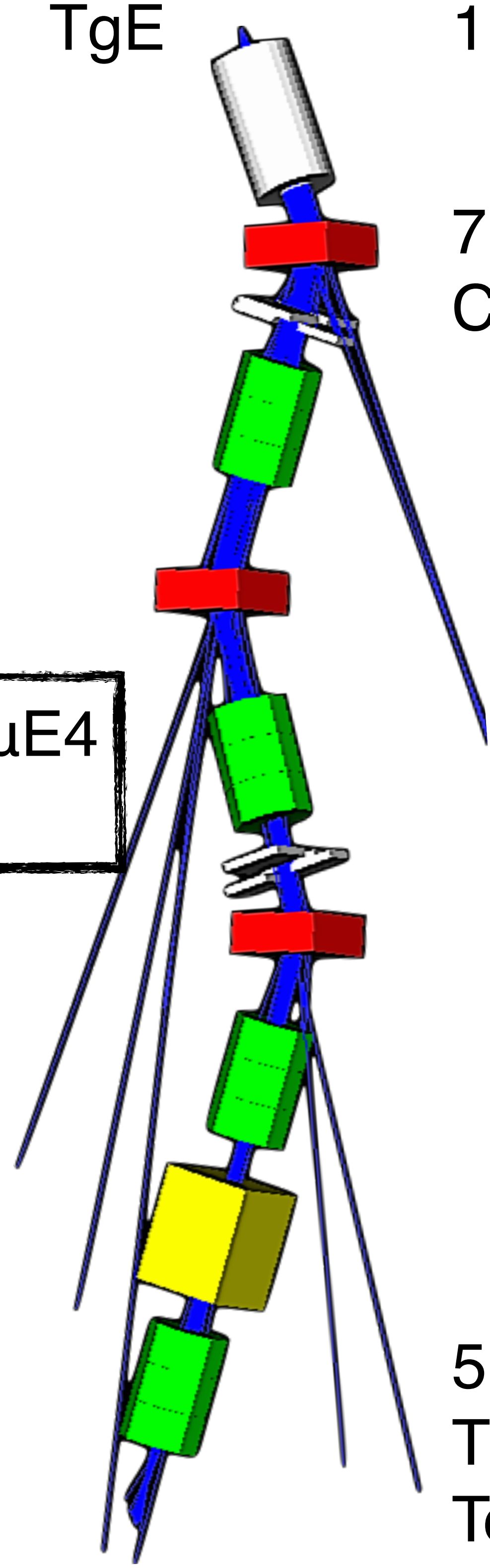
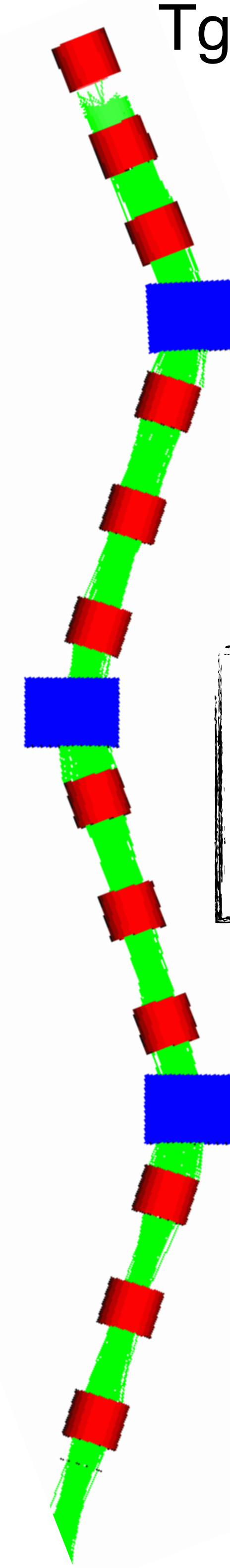


Existing µE4 beamline

	TgE		TgM*
Source	$1.2 \times 10^{11}\ \mu^+/s$		$1.3 \times 10^{11}\ \mu^+/s$
Capture	$7.2 \times 10^{9}\ \mu^+/s$ C ~ 6%		$3.4 \times 10^{10}\ \mu^+/s$ C ~ 26%
Transmission	$5 \times 10^{8}\ \mu^+/s$ T ~ 7% Total ~ 0.4%		$1.3 \times 10^{10}\ \mu^+/s$ T ~ 40% Total ~ 10%

⇨ Gain due to high capture and transmission efficiency

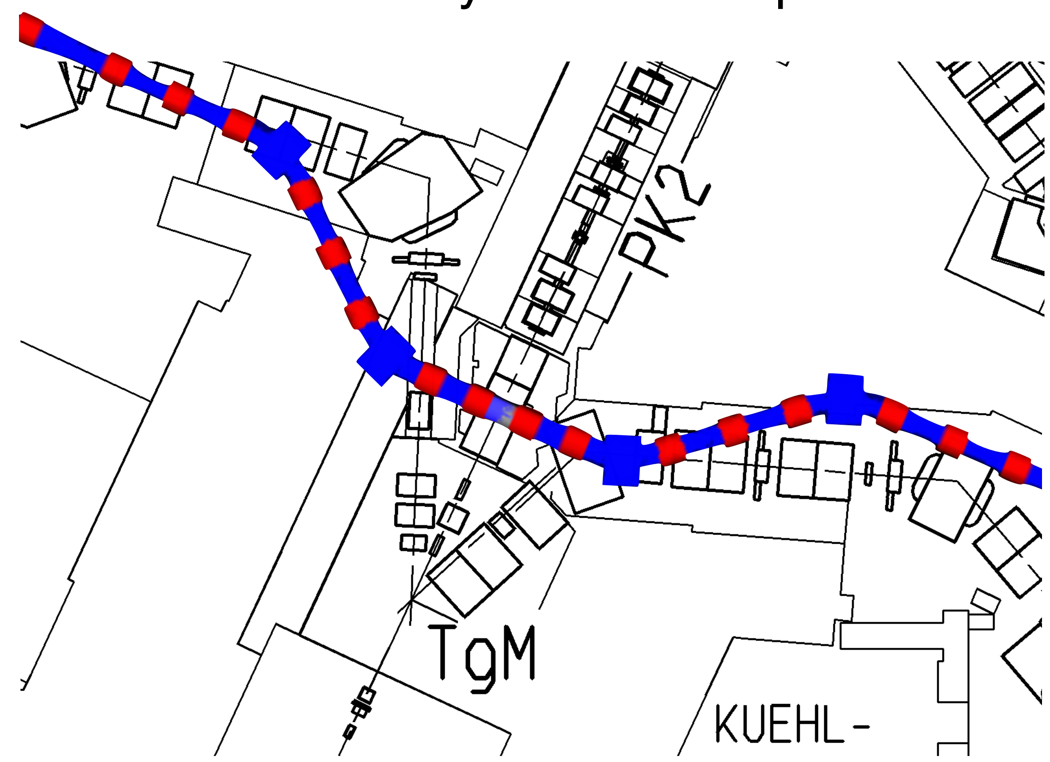


Proposed solenoid beamline

Solenoid Beamline: HiMB@EH

- Still lots to do!
  - Beam:
    - Final beam optics
    - Beam spot at final focus
    - Performance of separator
    - …
  - Target:
    - Slanted target within small gap
    - Change of target station
    - New shielding and beam channels
    - Disposal of highly radioactive material
    - …

Schematic of the layout in the experimental hall



- But exciting prospect and certainly worth the effort!

Conclusions

- Interesting physics opportunities for particle physics and materials science using high-intensity and high-brightness muon beams

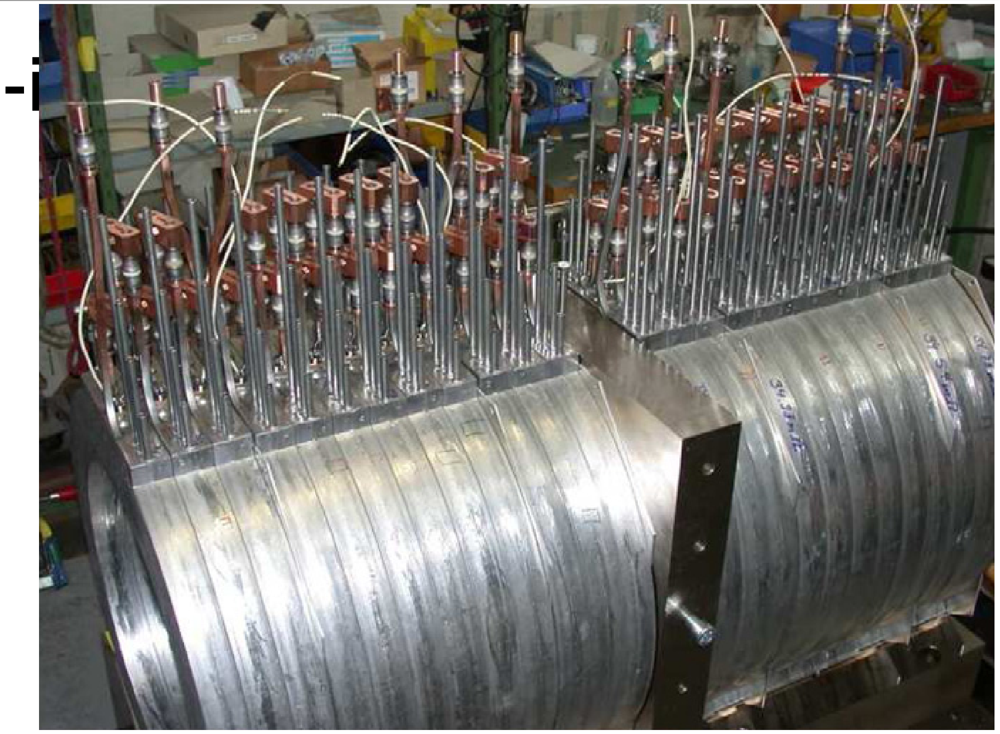
- The HiMB project explores the possibilities and feasibility of generating a high-intensity surface muon beam at PSI aiming at an intensity of 10^{10} μ^+/s.

- Initial simulations of a solenoid channel coupled to a 20 mm slanted target shows the potential to reach such an intensity.

Backup

muE4 Solenoids

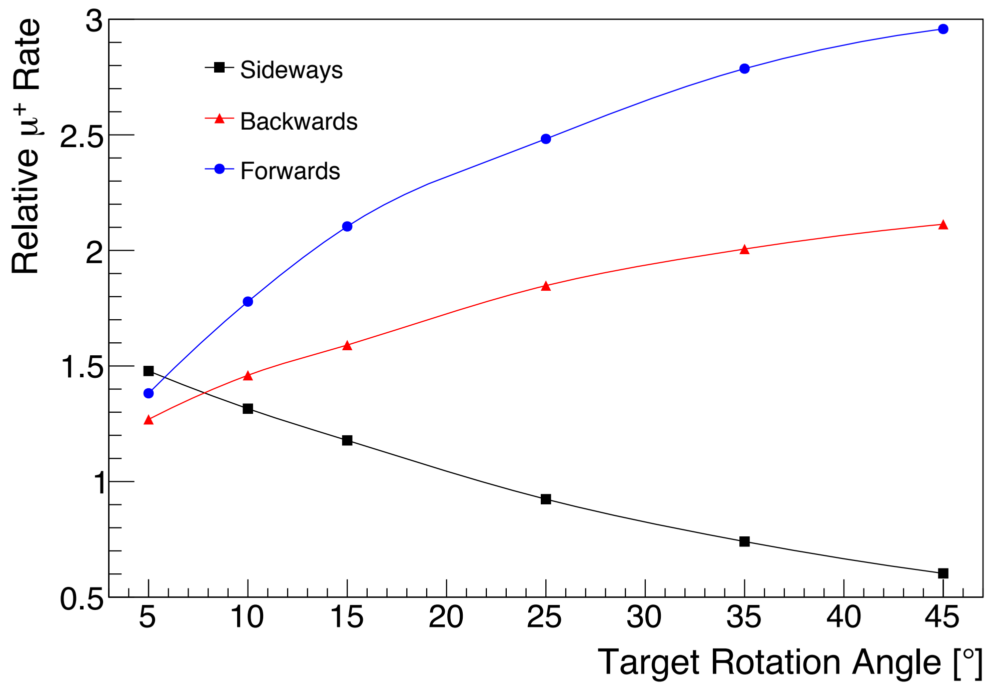
- 2 x 12 separate radiation-hard coils (mineral-i
- Iron housing
- Aperture: 500 mm
- Length: 2 x 750 mm
- Central field: 0.34 T / 0.27 T
- Roughly 20 kW each

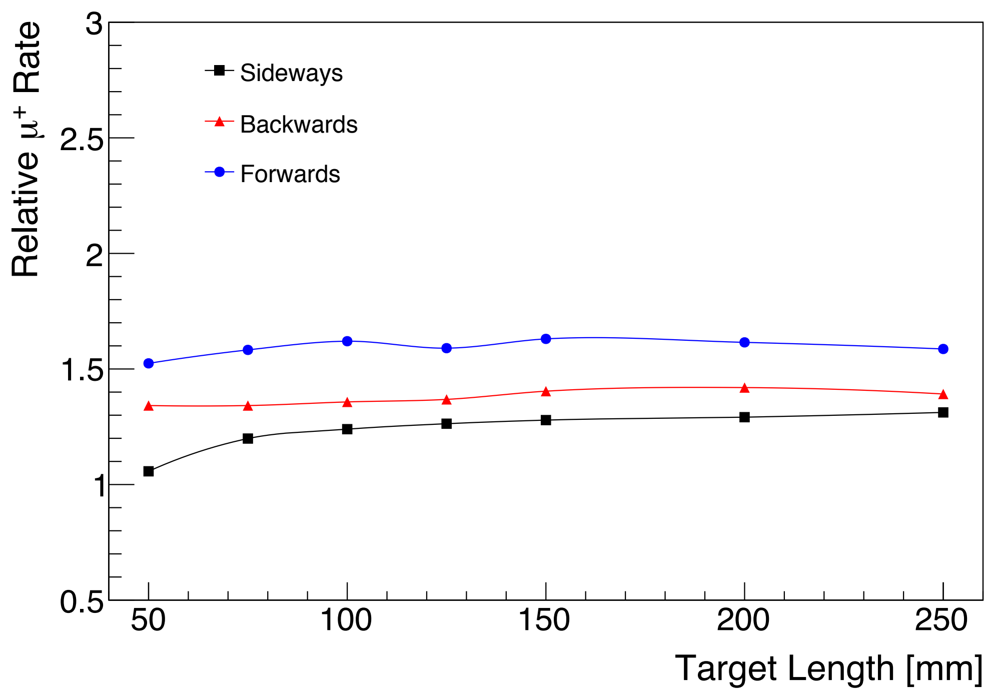


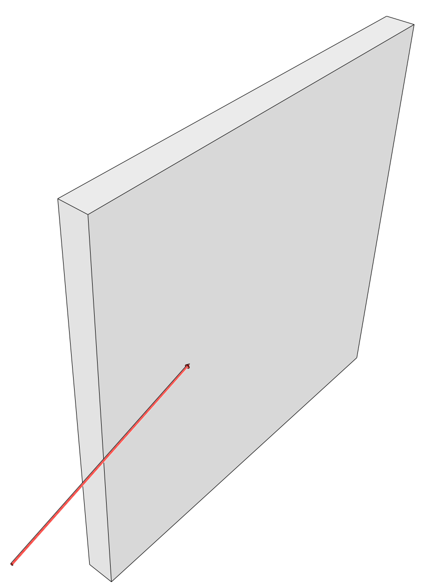
⇨ Design of a solenoid with similar characteristics existing
Not all solenoids will need to be radiation-hard

Slanted Target

- Rotation of the target can lead to significant increases to muon rates
  - Rotation direction determines which beamline receives increased rate
- Total target length has minimal affect on the muon rates in all directions.
  - Target length in beam direction is fixed (40 mm)







Pion Stop Densities