Improvements of the conventional M2 beam for more kaons at the AMBER Target

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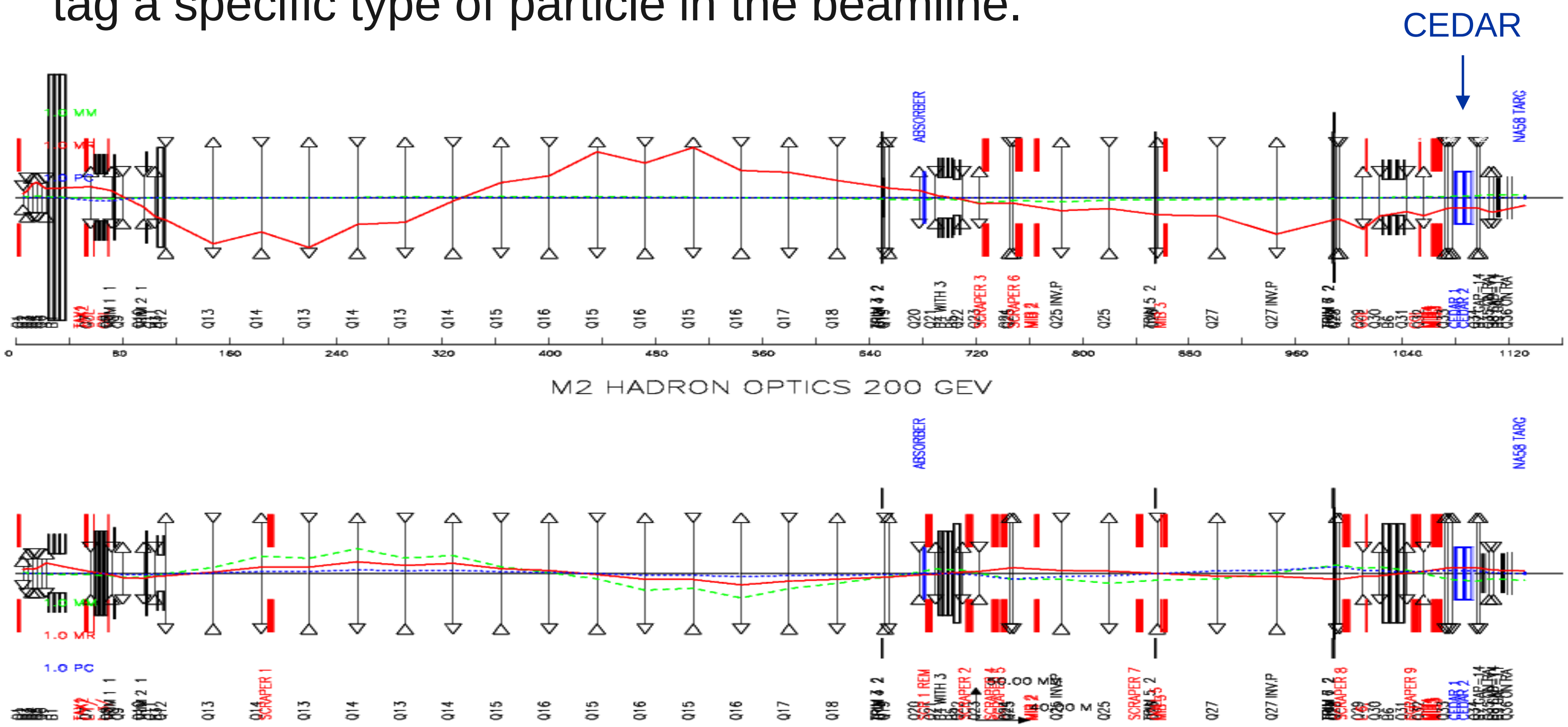
M2 Beam

- Currently the M2 beamline serves the COMPASS experiment with high-energy and high-intensity muon or hadron beams. (+ lower energy tertiary electron beams)
- The switching between the modes is fast and does not require additional installation.
- In the hadron mode an optional pair of differential Cherenkov counters (CEDARs) are available to tag a specific type of particle in the beamline.

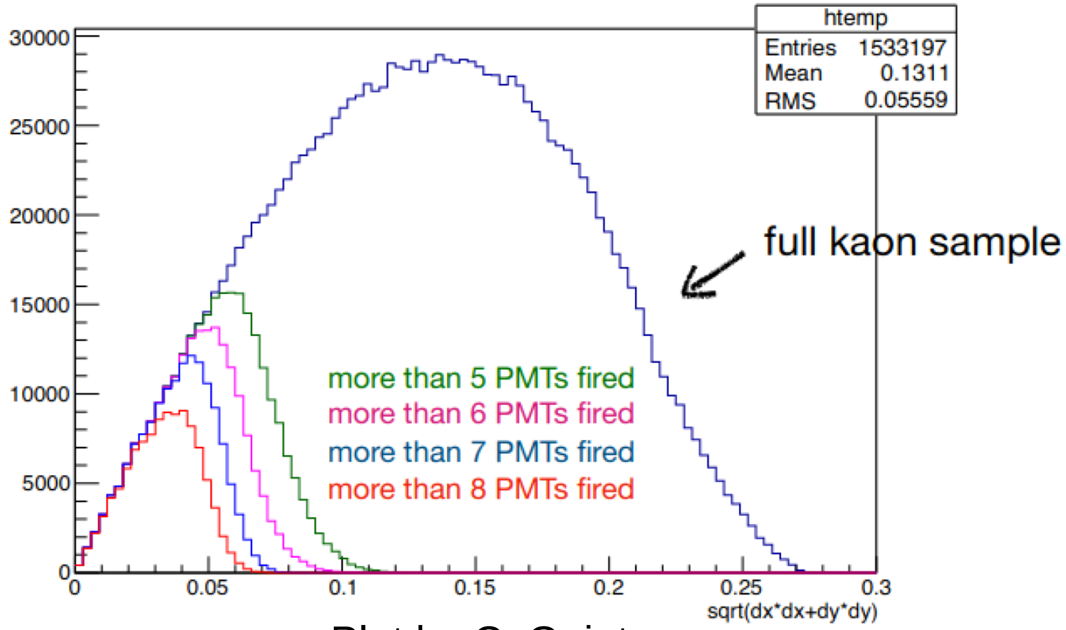


Hadron Beam

Parameter	Measured
Beam Momentum	< 280 GeV/c
Hadron flux at COMPASS per SPS cycle	< 10^8 (RP Limit)
Typical spot size at COMPASS target (σ_x x σ_y)	~ 5 mm x 5 mm

M2 conventional beam for future Drell-Yan programme

- Currently for specific conditions the instantaneous intensity of the hadron beam can be increased to 4.8x10^8 particles/spill (RP) → only allowed for Drell Yan runs with target absorber and the muon filter 3 iron block must be removed.
- The conventional hadron beam contains about 2.4% kaons corresponding to ~ 10^7 kaons/spill.
- High kaon tagging efficiency for the CEDARs is therefore required for the K-induced DY measurement.
- The tagging efficiency is dependent on the the beam divergence at the CEDARs.
- To improve the number of identifiable kaons at AMBER the options checked are *(RF- Separated beam not included here → see A. Gerbershagen's presentation)* :
  - Optimising the hadron beam in terms of divergence to increase the tagging efficiency of the CEDARs.
  - Increasing the number of accumulated hadrons on the AMBER target to 3x10^{14} per year (RP considerations).



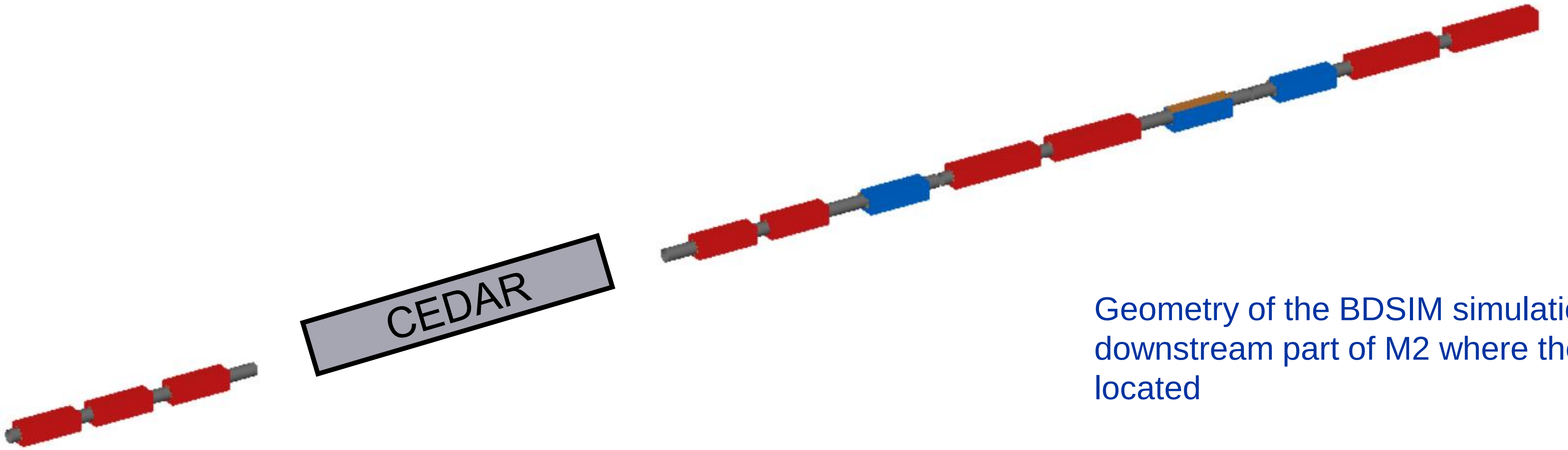
Plot by C. Quintans
AMBER DY-Meeting 30.11.2021

Optimising the conventional hadron beam
Multiple Scattering due to air

F. Metzger BE-EA

Current situation

- Currently there are ~ 80 m air along the beamline including nine Scrapers which are magnetic collimators where vacuum integration is costly and challenging.
- The air section adds ~ 35 µrad to the divergence from multiple scattering.
- There are also beam instrumentations like MWPCs, Scintillators which also contribute to the multiple scattering.
- In order to estimate the improvement with vacuum replacing the air sections, the whole beamline was simulated with BDSIM.
- The initial secondary beam was made larger than the transverse and longitudinal beam acceptance so the relative transmission is independent of initial beam assumptions.



Geometry of the BDSIM simulation showing the downstream part of M2 where the CEDARs are located

Results from BDSIM simulation

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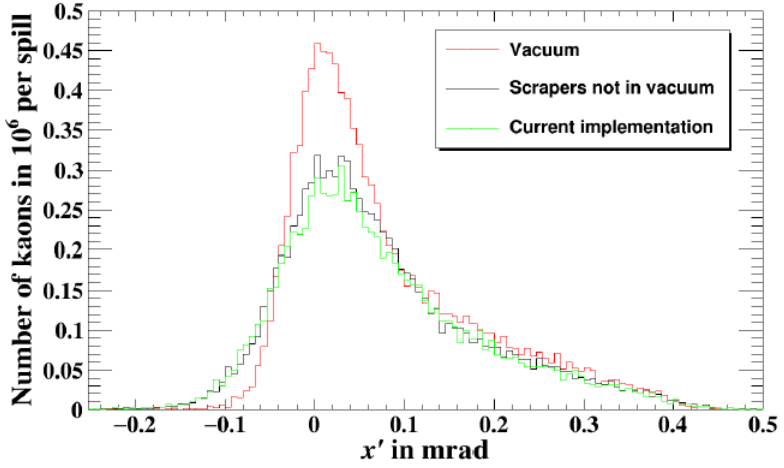
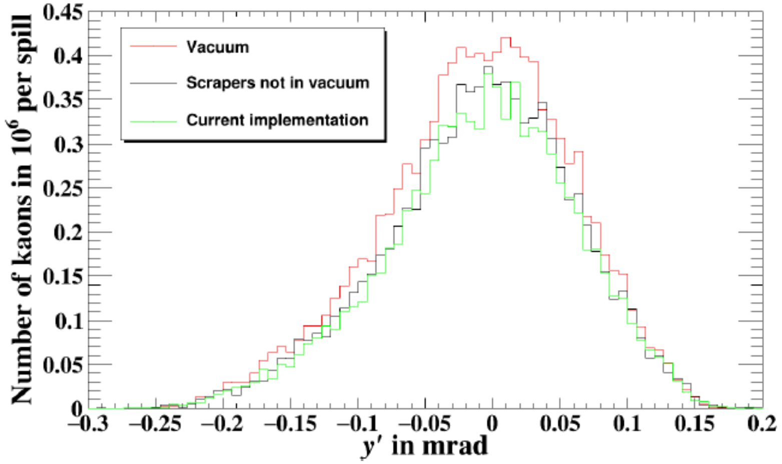


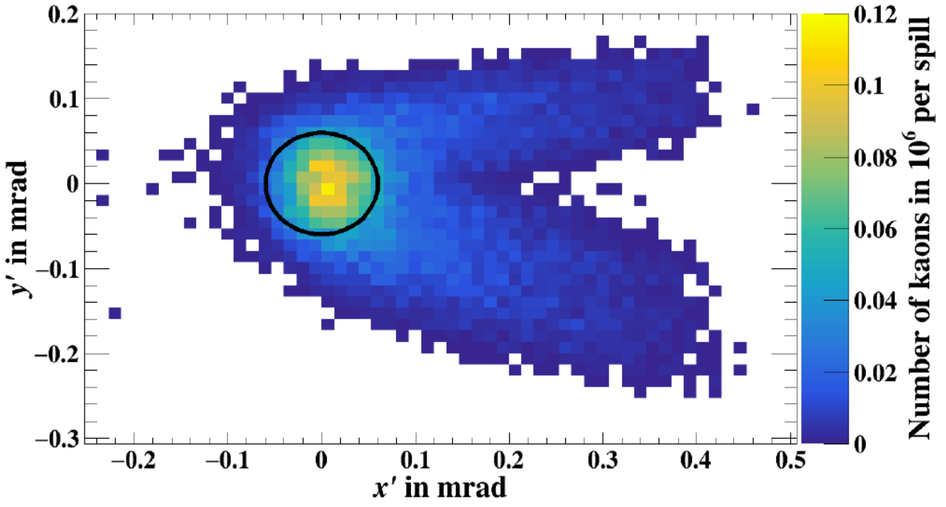
$\sigma_{x'}$ = 102.5 µrad, 109.3 µrad, 110.3 µrad



$\sigma_{y'}$ = 70.2 µrad, 69.7 µrad, 69.8 µrad

- Three options checked: Current configuration; Full vacuum; Scrapers not in vacuum.

- The standard deviation of the divergence does not improve much.
- With full vacuum the overall transmission is 20% more.
- With Scrapers not in vacuum the improvement in the overall transmission is 5%.



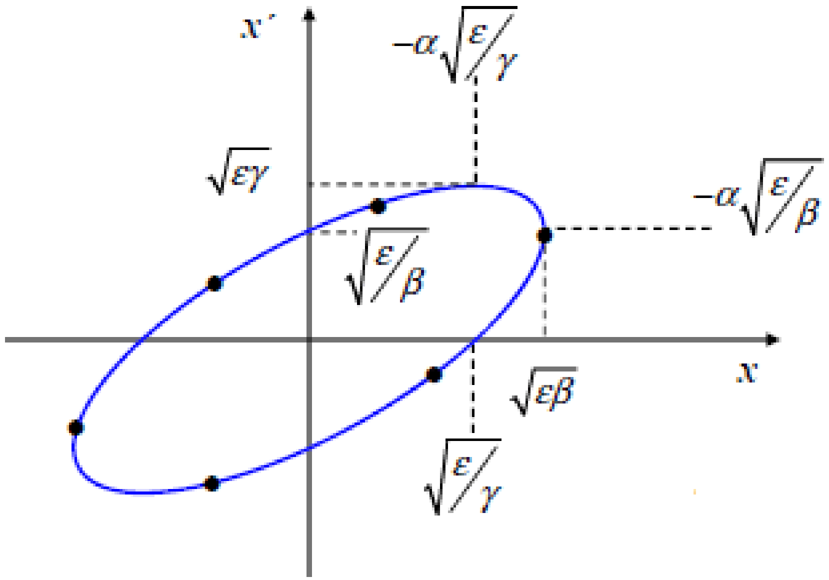
- For a particle to be tagged at the CEDARs **r' =** $\sqrt{x'^2 + y'^2} \leq$ **60 µrad**
- Current implementation ~ 2.7 x 10^6 kaons per spill
- Scrapes not in vacuum ~ 3 x 10^6 kaons per spill → 11% improvement
- Full vacuum ~ 4 x 10^6 kaons per spill → 48% improvement

Optimising the conventional hadron beam

Beam Optics

Improvements to the divergence

- The phase space (x'-x/y'-y) of the beam is constant, improving divergence → larger beam size.
- Two options were studied:
  - New collimation to cut down the tails of the divergence for the horizontal plane.
  - Improved optics with larger beam size in Y and thus smaller divergence for the vertical plane.
- The optics design was based on the test by L. Gatignon in 2009.



Improvements to the divergence

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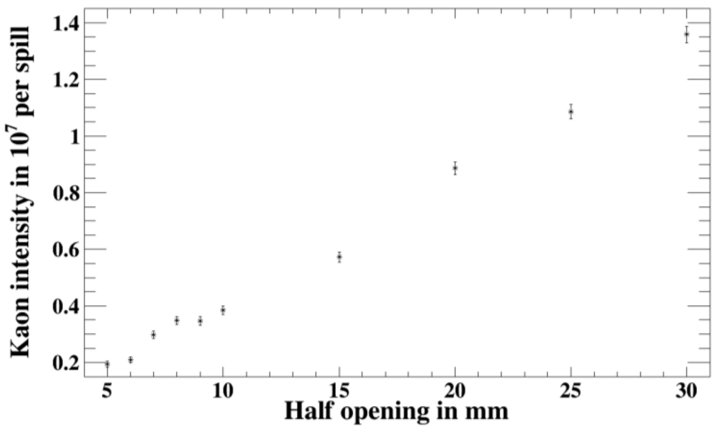
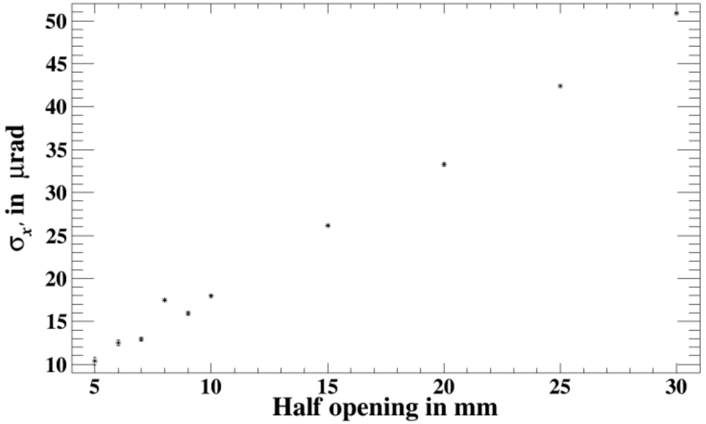
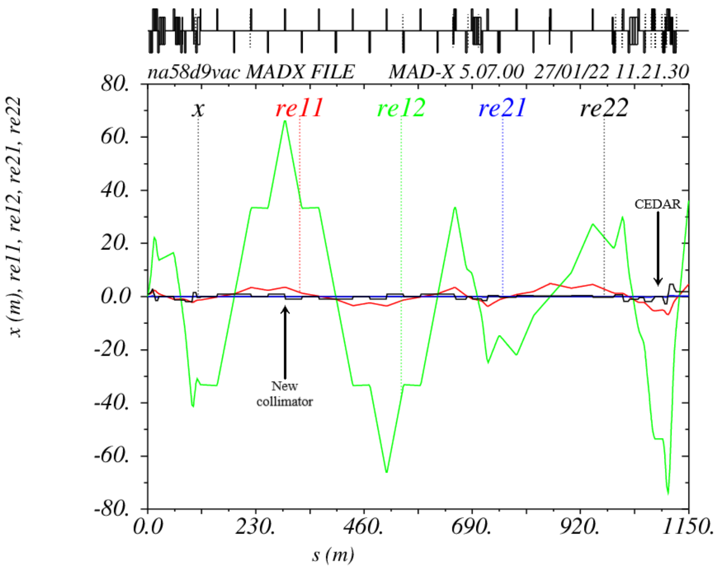


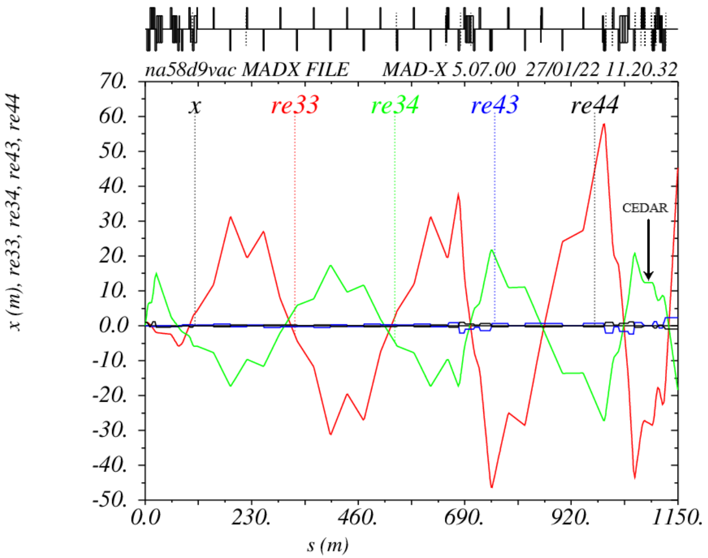


- The collimator is placed at a location with large horizontal beam size.
- By closing the collimators from 30 mm to 15 mm, divergence and overall intensity decreases by 50%.
- Vertical collimation shows small improvement as M2 is a vertically bending beam line so there is dispersion in Y.
- The effect of collimation in X is therefore limited by the vertical divergence as the figure of merit is

$$r' = \sqrt{x'^2 + y'^2}$$

- For the vertical plane it is possible to decrease the divergence to $\sigma_{y'}$= 53 µrad by increasing the beam size at the CEDARs.





Results from the divergence improvemnt

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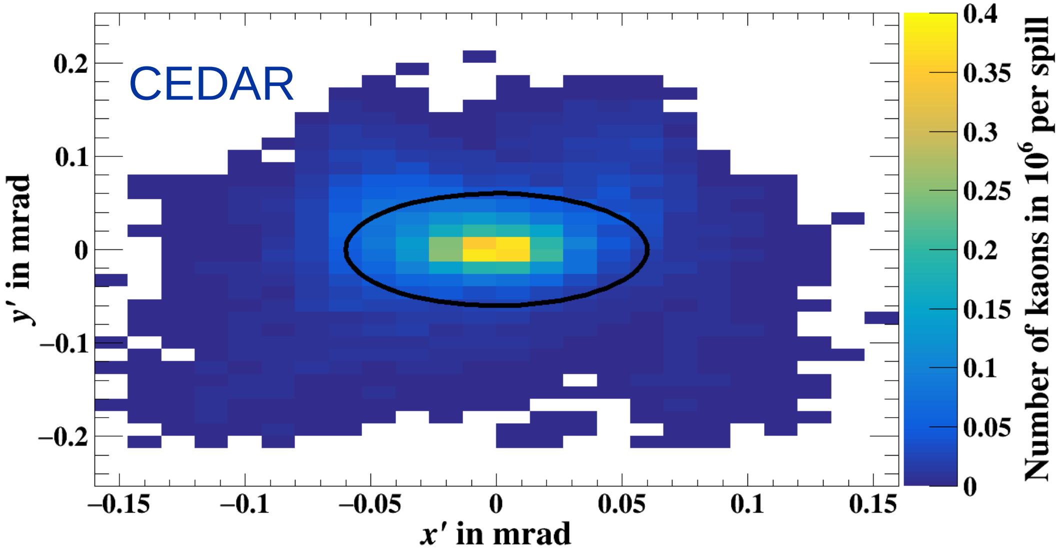
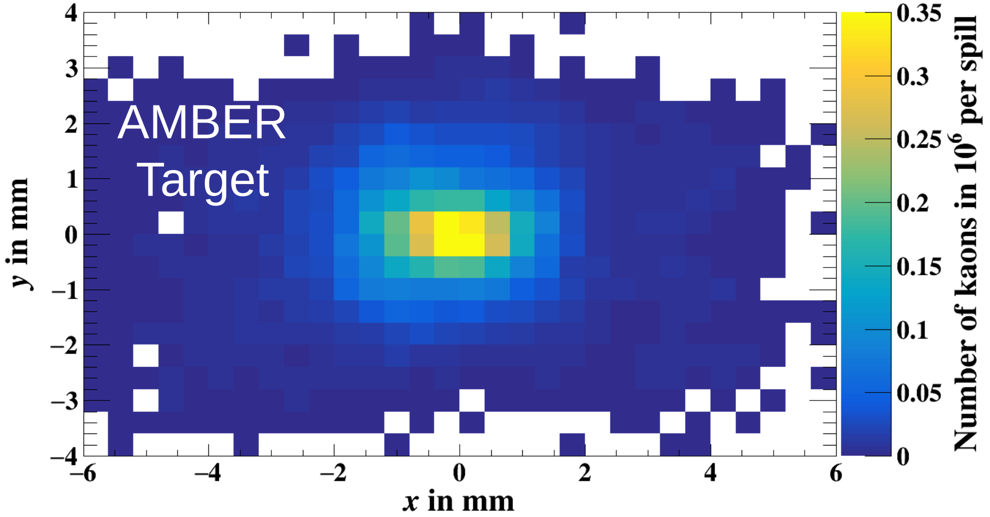




- With the improvements in the horizontal collimation and larger beam size in the y-plane (for full vacuum):

  7x 10^6 kaons per spill within 60 μrad

  (from 2.7 x 10^6 in the current scenario)
- This corresponds to 70% of the total kaon intensity at the CEDARs for 4.8 x 10^8 hadrons/spill.
- Focussing of the beam at the AMBER target has also been checked

  σ_x= 1.4 mm σ_y= 1 mm

Increased intensity

Radiation Protection study

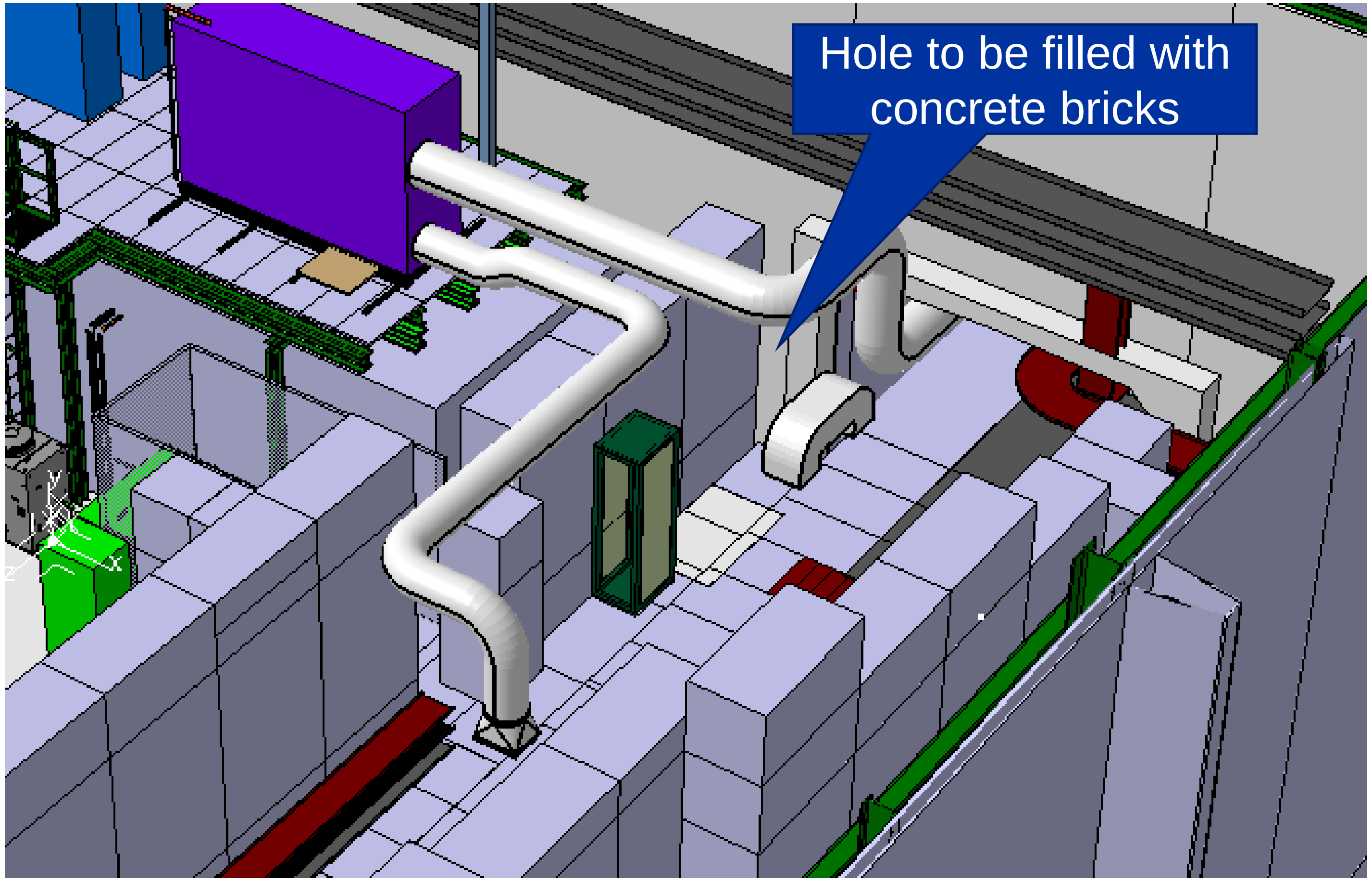
A. Devienne, C. Ahdida HSE-RP

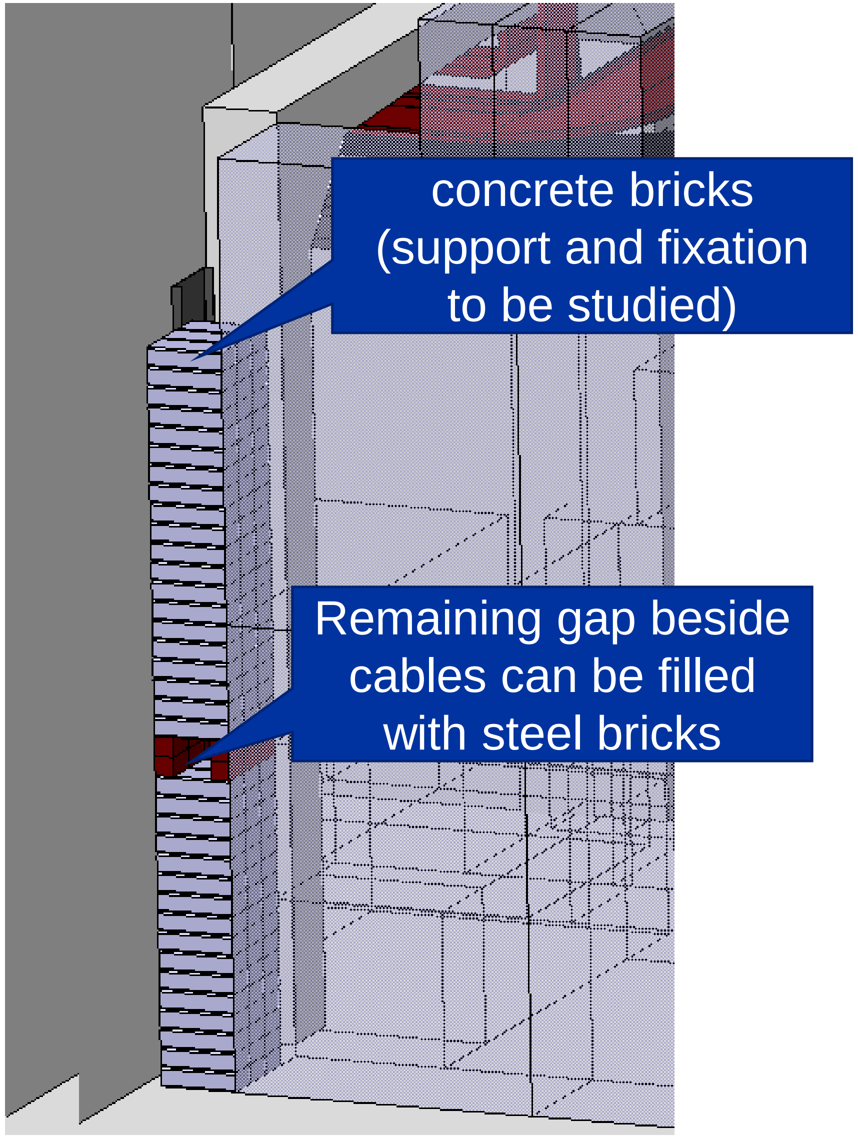
Increased annual intensity

- In order to improve the accumulated kaons the beam intensity increase was also studied.
- RP studies were performed to check additional shielding for higher intensities to comply with the radiation area classification, calculate prompt radiation, skyshine optimisation and environmental impact.
- The source term used included 190 GeV/c π- beam with an instantaneous intensity of 4.8×10^{8} π-/spill and 240 spills/h on the AMBER target.
- The aim was to validate the increase of the accumulated annual intensity to 3×10^{14} π-/year on the AMBER target.

Proposed modifications

S. Girod BE-EA

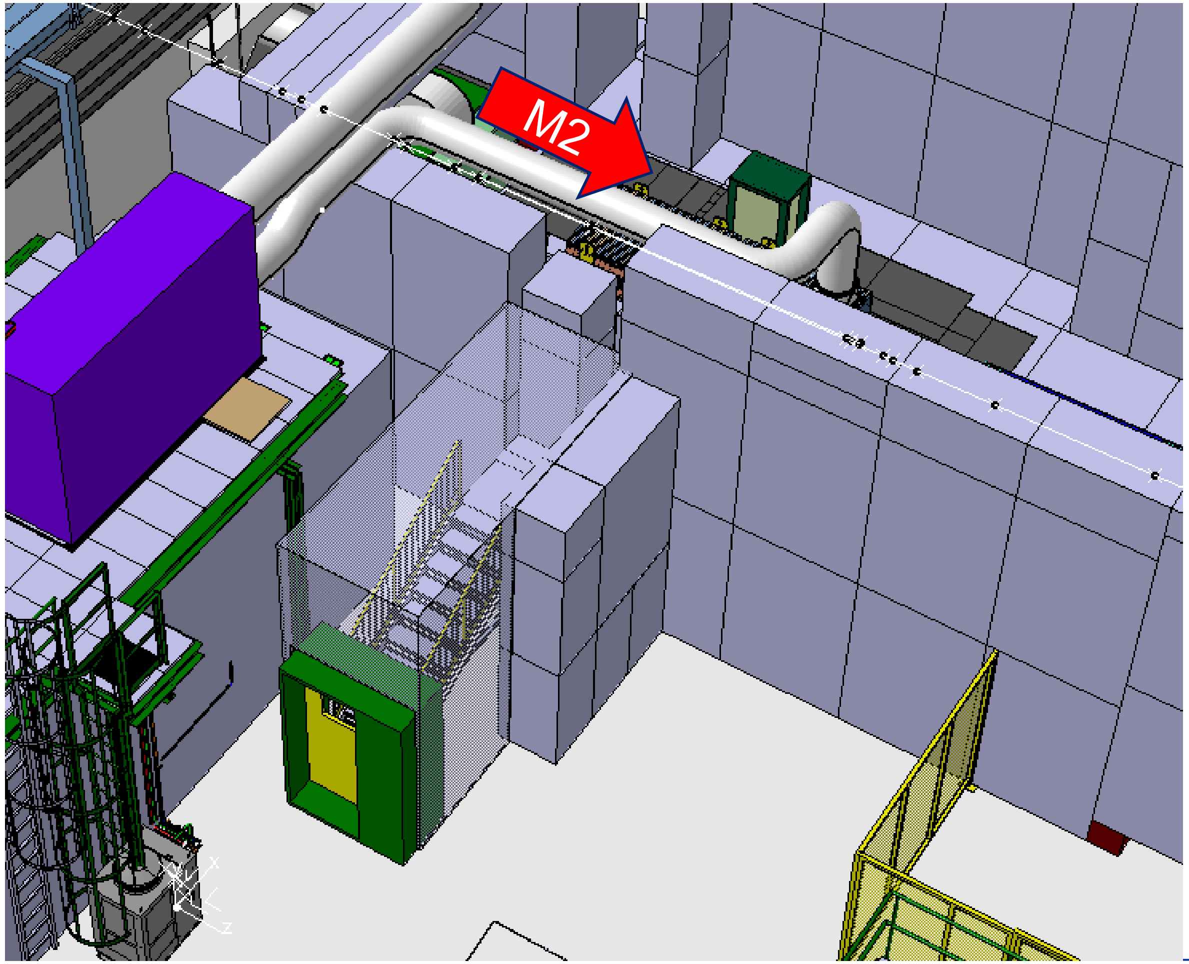




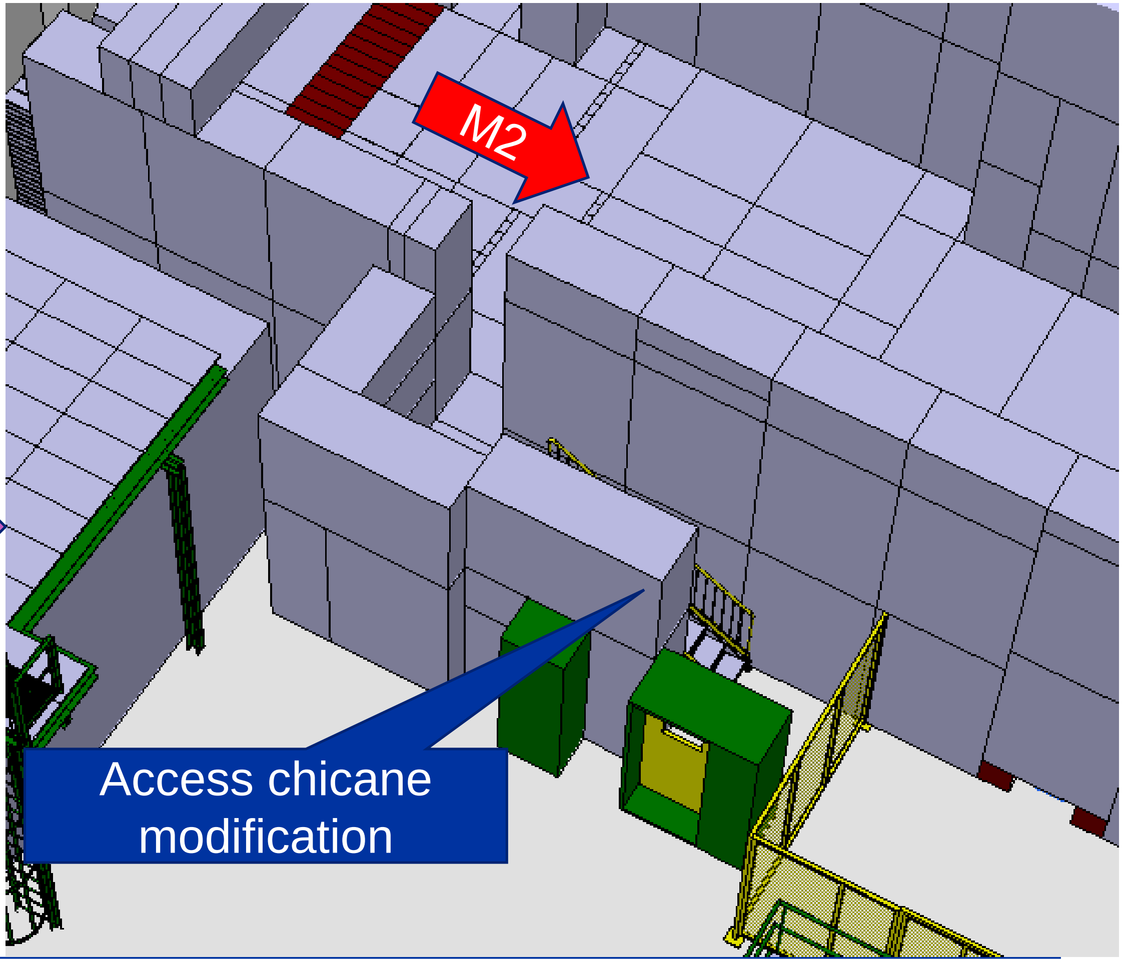
S. Girod BE-EA

Proposed modifications

Today



Proposal

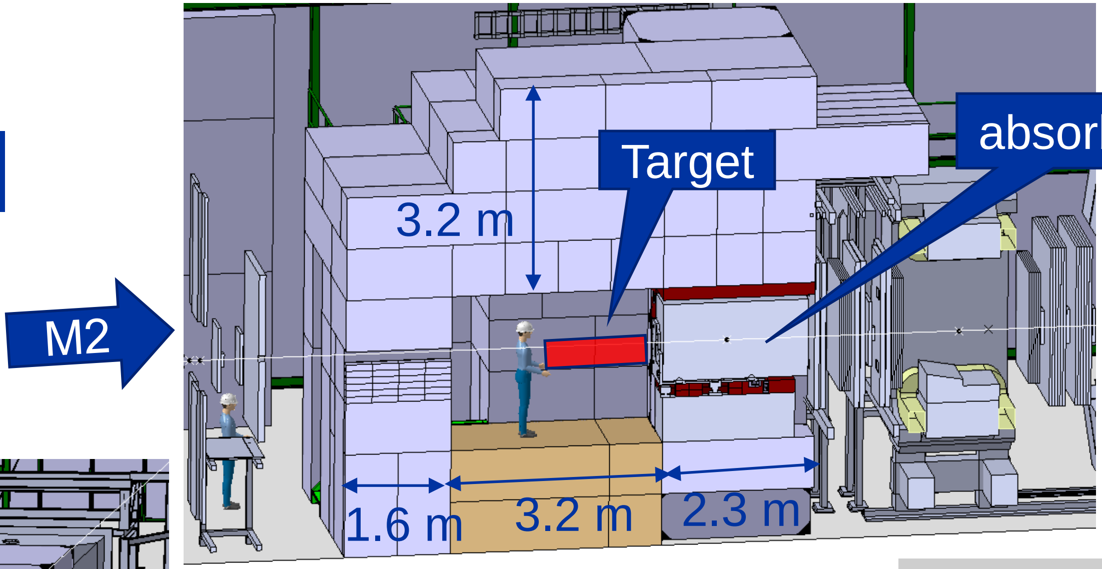


Proposed modifications

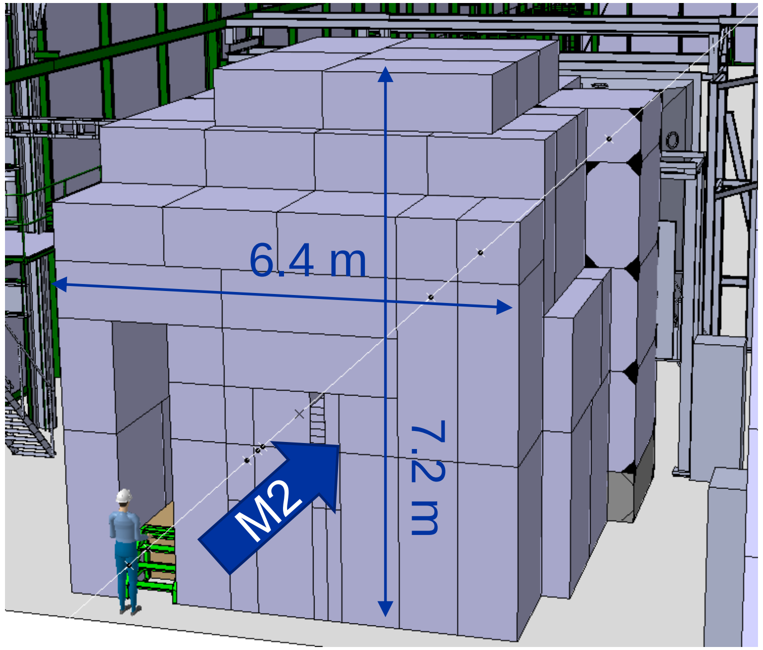
S. Girod BE-EA

Target Bunker

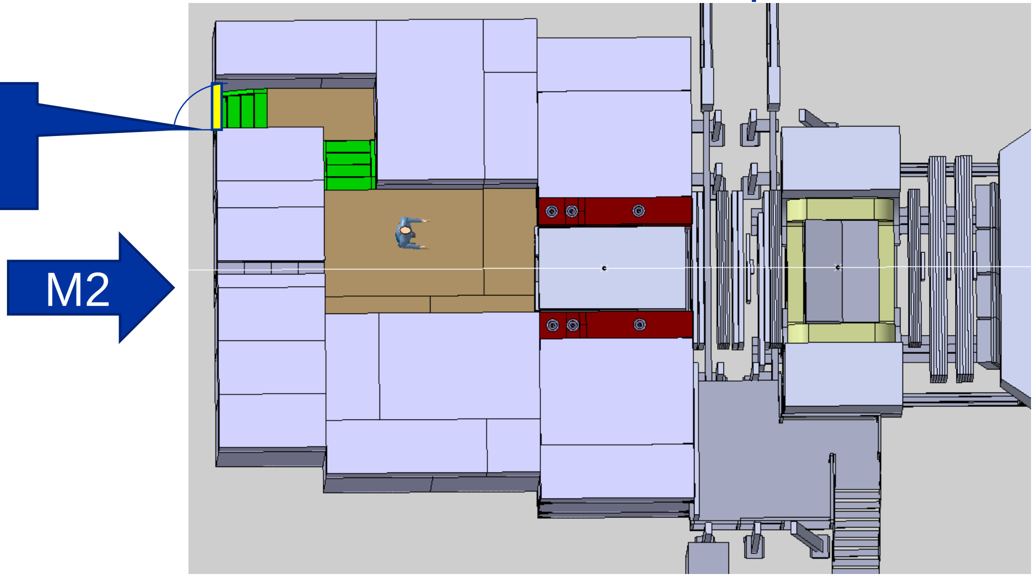
Side View



Front View



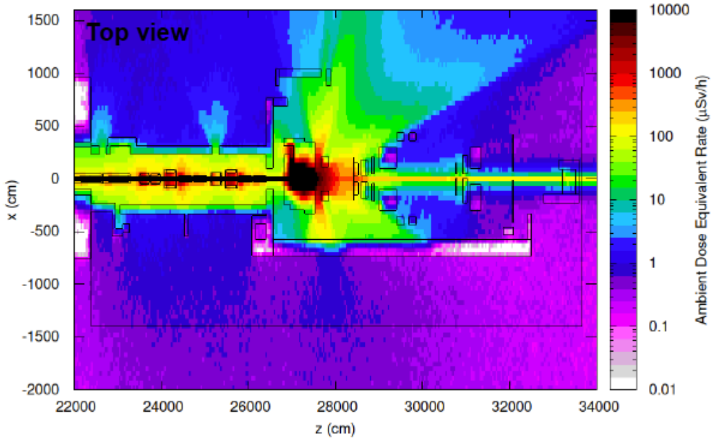
Top View

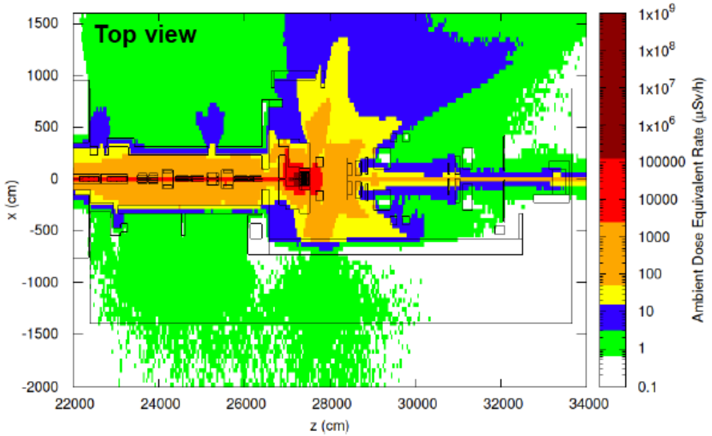


A. Devienne, C. Ahdida HSE-RP

Results from RP simulations

Prompt ambient dose equivalent rate (µSv/h) for 4.8 x 10^8 π-/spill and 240 spills/h on Target

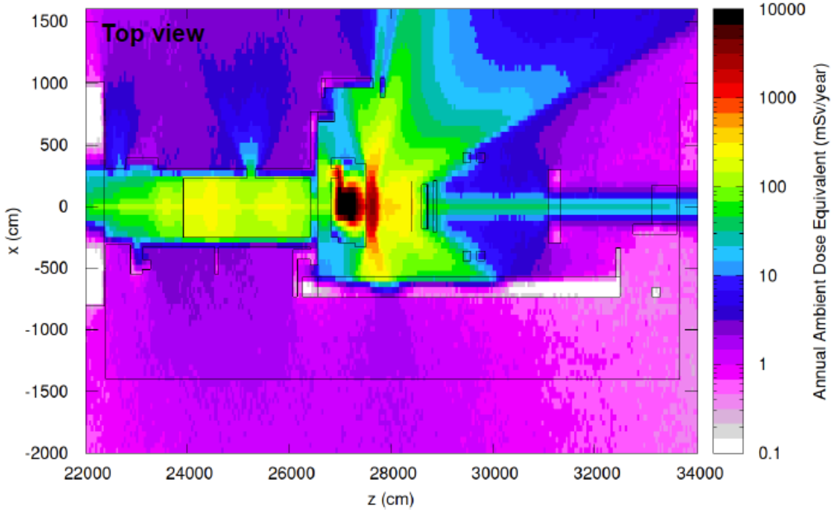




Area	Annual dose limit (year)	Ambient dose equivalent rate: permanent occupancy	Ambient dose equivalent rate: low occupancy	Sign
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
Supervised	6 mSv	3 µSv/h	15 µSv/h	
Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	
Limited Stay	20 mSv	-	2 mSv/h	
High Radiation	20 mSv	-	100 mSv/h	
Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY DÉFENSE D'ENTRER

Radiation Area; Controlled Area

Prompt annual ambient dose equivalent rate (mSv/h) for 3 x 10^{14} π-/year on Target



- The beamline has been simulated in FLUKA with the proposed modifications.
- Results show the proposed shielding design is in agreement with radiation area classification.
- Air activation for access in EHN2 hall is negligible.
- Annual activity in all air volumes is below 0.1 TBq/y for 3 x 10^{14} π-/year on target.
- Exposure of members of the public due to air releases is below 0.1 µSv/y.

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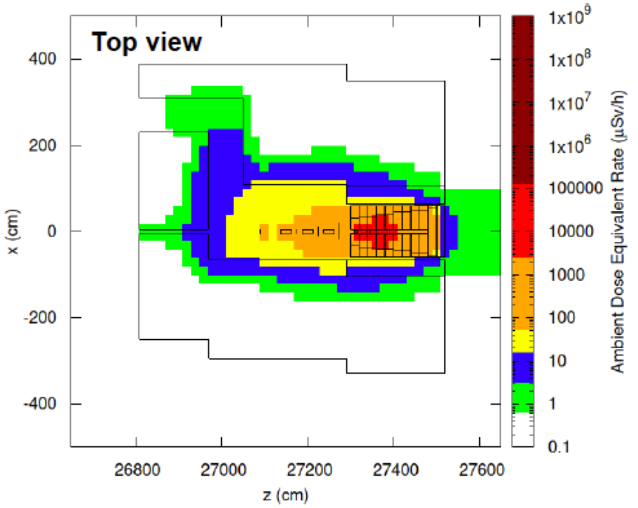
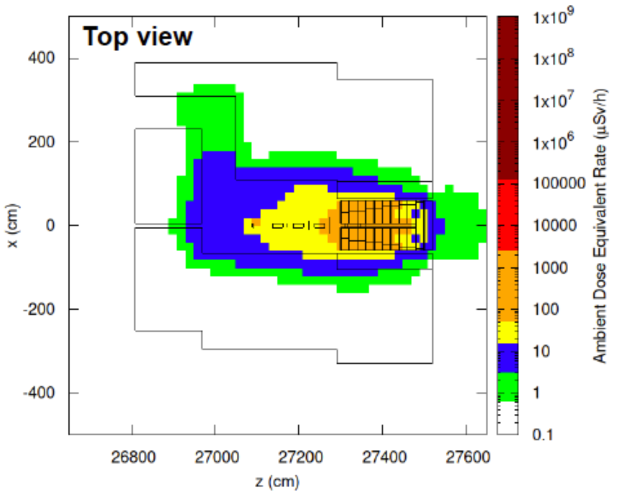
Results from RP simulations



2 minutes

(minimum time from access system)



1 hour

Area	Annual dose limit (year)	Ambient dose equivalent rate: permanent occupancy	Ambient dose equivalent rate: low occupancy	Sign
Non-designated	1 mSv	0.5 µSv/h	2.5 µSv/h	
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Simple Controlled	20 mSv	10 µSv/h	50 µSv/h	
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High Radiation	20 mSv	-	100 mSv/h	
Prohibited	20 mSv	-	> 100 mSv/h	NO ENTRY DÉFENSE D'ENTRER

Radiation Area / Controlled Area

- The residual ambient dose equivalent rate has also been checked for 6-month irradiation at 4.8 x 10^8 π-/spill and 240 spills/h on target for a 2 minute cool-down and a 1h cool down time.
- To optimise the access to the bunker a PMI monitor will be requested to monitor the residual dose rate inside the bunker before access.

Conclusions

- Optics and RP studies have been done to improve the divergence of the M2 hadron beam and the overall accumulated intensity on target to increase the number of identifiable kaons at AMBER.
- By adding vacuum to the beamline the transmission can be improved by 20% for the full vacuum and 5% when the scrapers are not in vacuum.
- For the option of full vacuum the number of identifiable kaons increases by 48% compared to the current scenario.
- By improving the collimation in the horizontal plane and increasing the beam size in the vertical plane the number of kaons identifiable within the 60 µrad is ~ 7 x 10^6 kaons/spill (from 2.7 x 10^6/spill) (from simulation → should be validated with data).
- New shielding for the upstream CEDAR location, modified access door for PPE211 and the target bunker design have been validated by RP.
- The proposed modifications are in agreement with the radiation area classification for an accumulated intensity of 3 x 10^{14} π/year on the AMBER target.
- An ECR is under preparation to prepare for the installation works for the shielding modifications which is being planned for the 2023/24 YETS.
- The technical solution and cost for the vacuum option is also being checked.

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