M2 Beamline optimization for Hadrons

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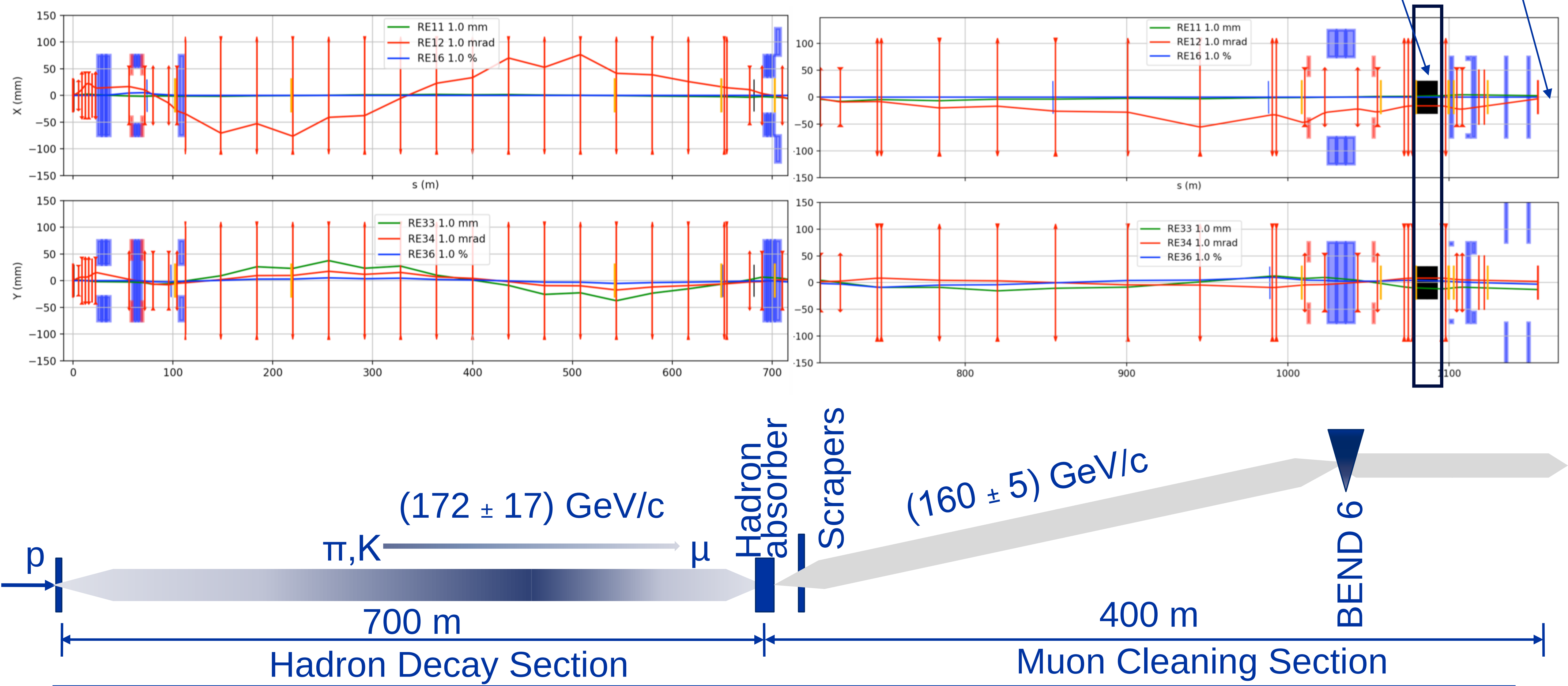
The M2 Beamline

The M2 Beam

- **The M2 beamline is ~ 1.1 km long transporting secondary particles from the T6 target to the EHN2 hall.**
- **It has a 700 m long hadron section to allow hadron decays to muons followed by 9.9 m Be inside a bend to absorb the hadrons with the muons passing through.**
- **A 400 m long muon section selects the final muon momentum and cleans the muon beam halo.**
- **M2 has three main operation modes:**
  - High-energy, high-intensity muon beam. Normally for muon momenta up to 160 GeV/c. Higher momenta up to 220 GeV/c are possible, but the flux drops very rapidly with beam momentum.
  - High-intensity secondary hadron beam for momenta up to 280 GeV/c with radiation protection constraints.
  - Low-energy, low-intensity (and low-quality) in-situ electron calibration beam.

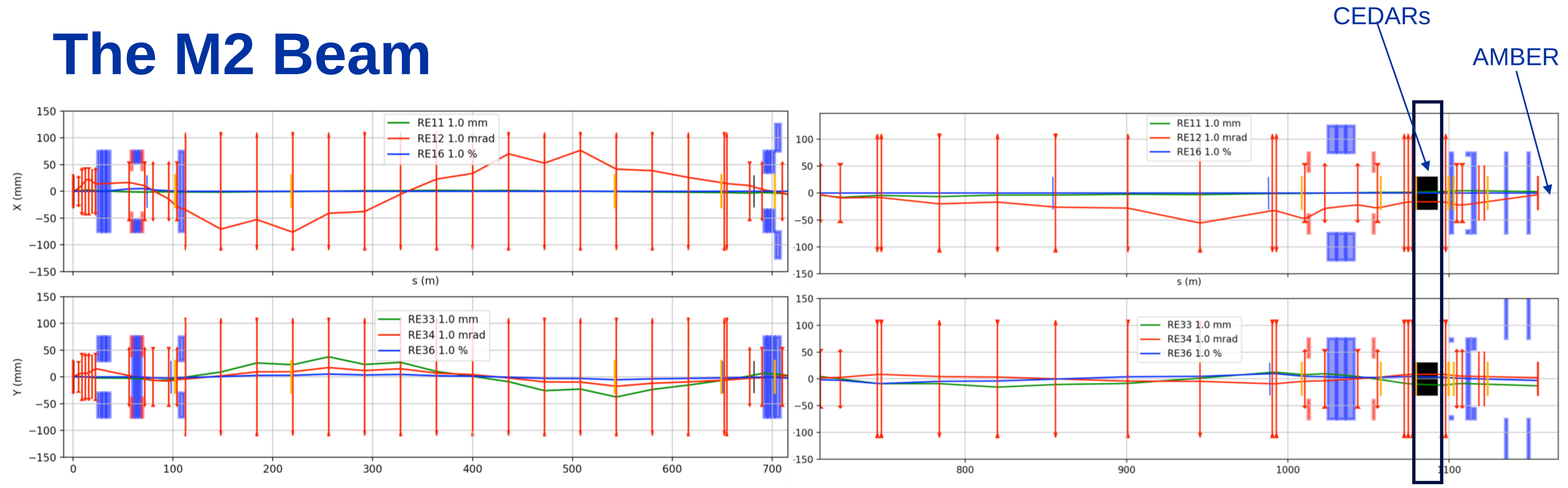
Beam Mode	Momentum (GeV/c)	Max. Flux (ppp / 4.8s)	Typical $\Delta p/p$ (%)	Typical RMS spot at COMPASS target	Polarisation	Absorber (9.9 m Be)	XCIO (5 mm Pb)
Muons	+208/190 +172/160	~10^8 2.5 10^8	3%	8 x 8 mm	80%	IN	OUT
Hadrons	+190 -190 Max. 280	10^8 (RP) 4 10^8 (with dedicated dump)	_	5 x 5 mm	_	OUT	OUT
Electrons	-10 to -40	< 2 10^4	_	> 10 x 10 mm	_	OUT	IN

The M2 Beam

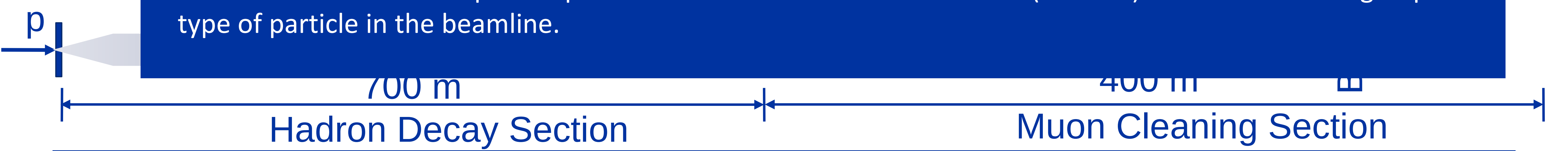


CEDARs
AMBER
RE11 1.0 mm
RE12 1.0 mrad
RE16 1.0 %
RE33 1.0 mm
RE34 1.0 mrad
RE36 1.0 %
X (mm)
Y (mm)
s (m)
(172 ± 17) GeV/c
p
π,K
μ
Hadron absorber
Scrapers
(160 ± 5) GeV/c
BEND 6
700 m
400 m
Hadron Decay Section
Muon Cleaning Section

The M2 Beam



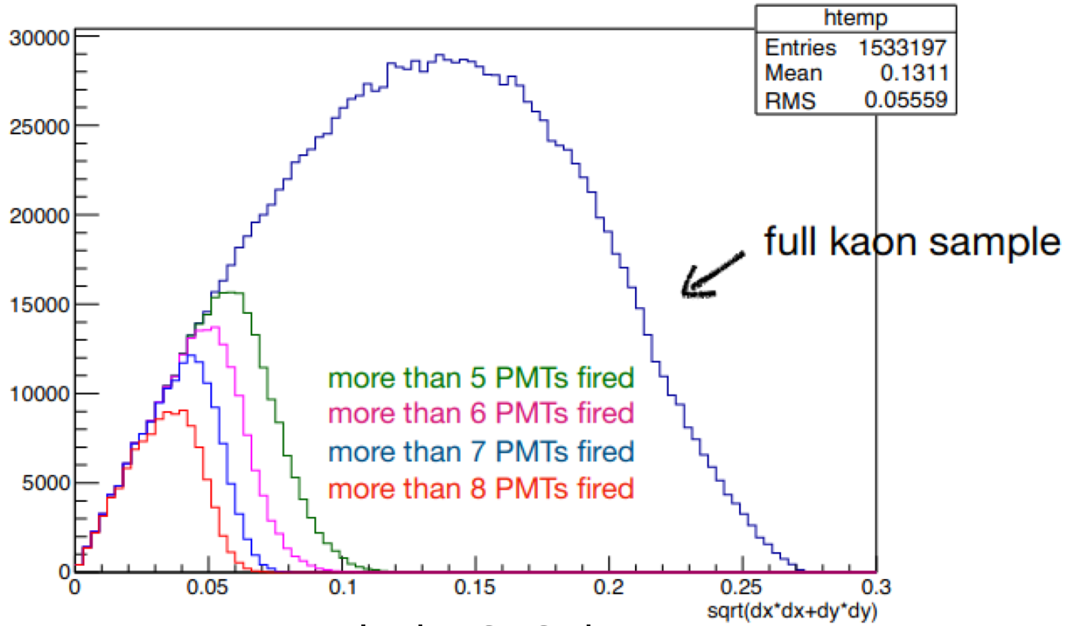
- The switching between the modes is fast and does not require additional installation (except installation of the CEDARs for the hadron runs).
- In the hadron mode an optional pair of differential Cherenkov counters (CEDARs) are available to tag a specific type of particle in the beamline.



M2 beam for future Drell-Yan programme

- Currently for specific conditions the instantaneous intensity of the hadron beam can be increased to 4.8×10^8 particles/spill (limited by RP) → only allowed for Drell Yan runs with target absorber and, the muon filter (3 iron blocks) 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:
  - Increasing the purity of kaons in the beam → RF-separation.
  - 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 3×10^{14} per year → RP considerations (*See C. Ahdida's talk*).

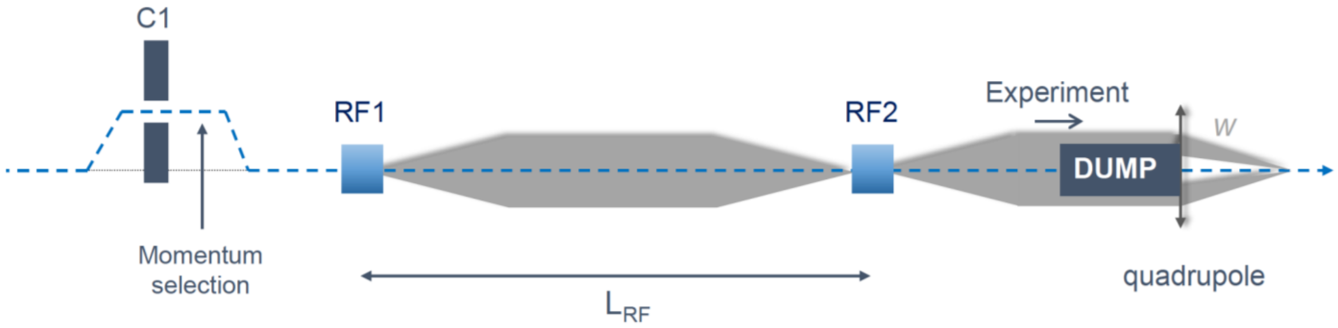


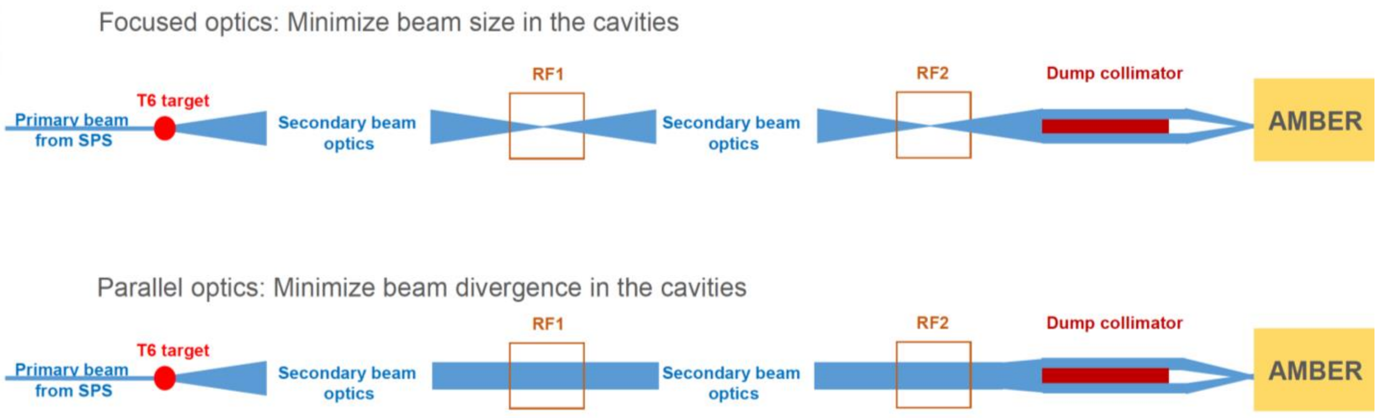
Plot by C. Quintans
AMBER DY-Meeting 30.11.2021

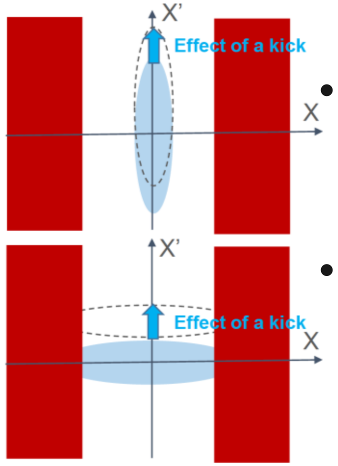
Short recap of RF-separated beam

RF separated beam

- Same momentum but different velocities translate to a time difference for different particle species.
- Time-dependent transverse kick by RF cavities in dipole mode translates this to a phase difference.
- RF1 kick compensated or amplified by RF2 depending on velocity, i.e., particle species.
- Dump stops the unwanted particles.



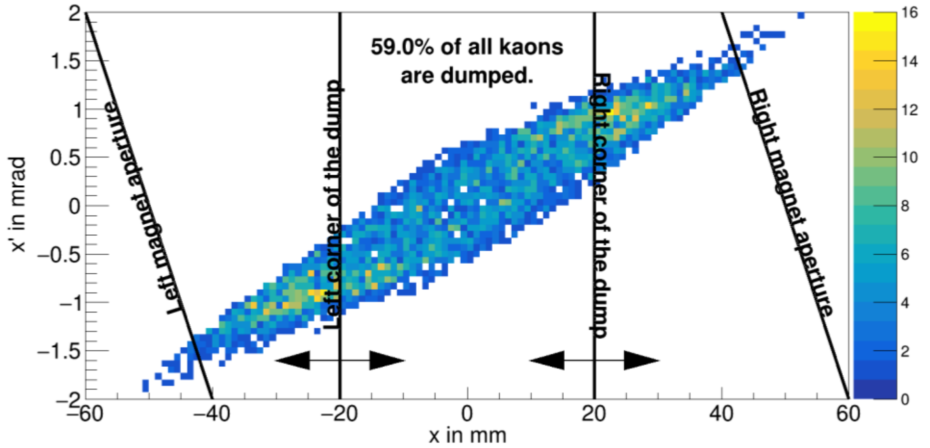




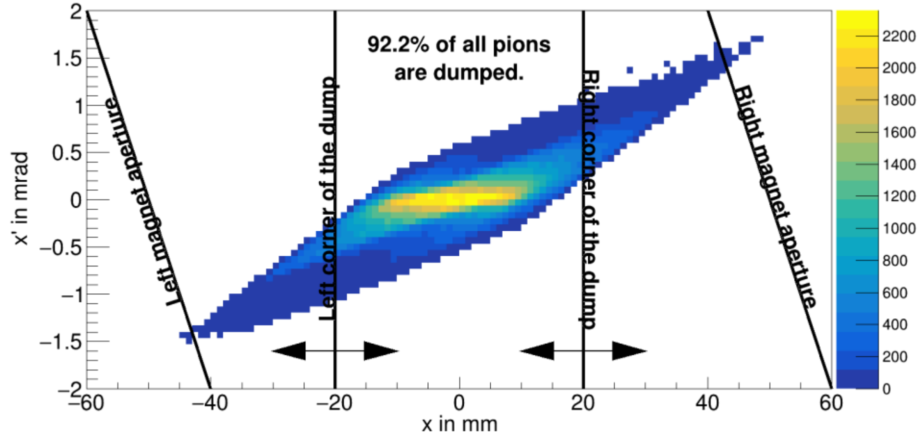
- Different optics were studied to maximise the acceptance in the cavities and the relative kick.
- Focussed beam
  - Maximum acceptance but small relative kick.
- Parallel beam
  - Beam limited by apertures.
  - Maximum relative kick.

Optics options for RF separated beam

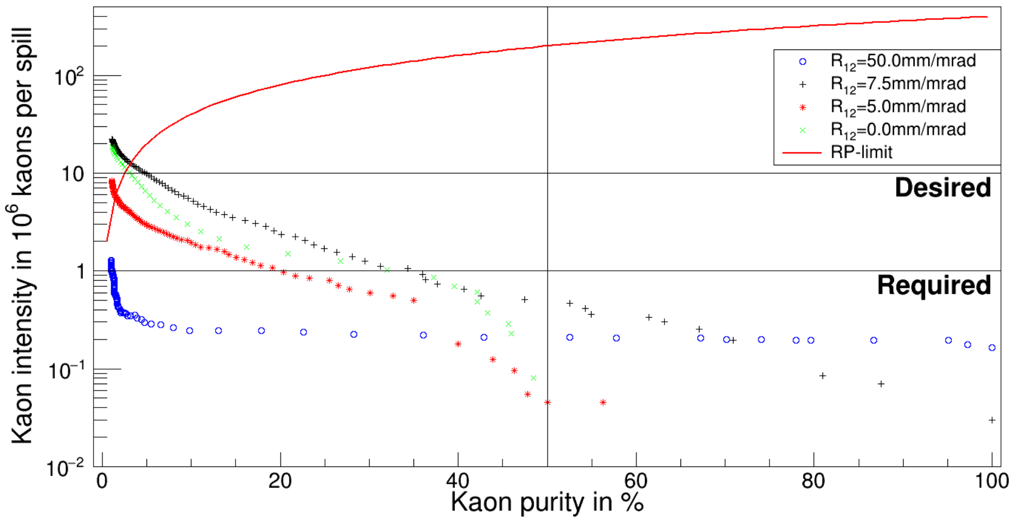
K^- phase space



π^- phase space



- A drift of 20 m creates the position separation at the beam dump due to the angular separation after RF2.
- Everything above red curve is forbidden by RP
- **With R12 = 7.5 mm/mrad 5×10^5 kaons per spill at 50% purity possible for 150 units on target.**
- CEDAR tagging efficiency not taken into account here.
- **Intensity too small for AMBER's Drell-Yan run.**
- **Study of the conventional hadron beam was therefore necessary to optimize the kaon transmission and tagging efficiency with CEDARs.**

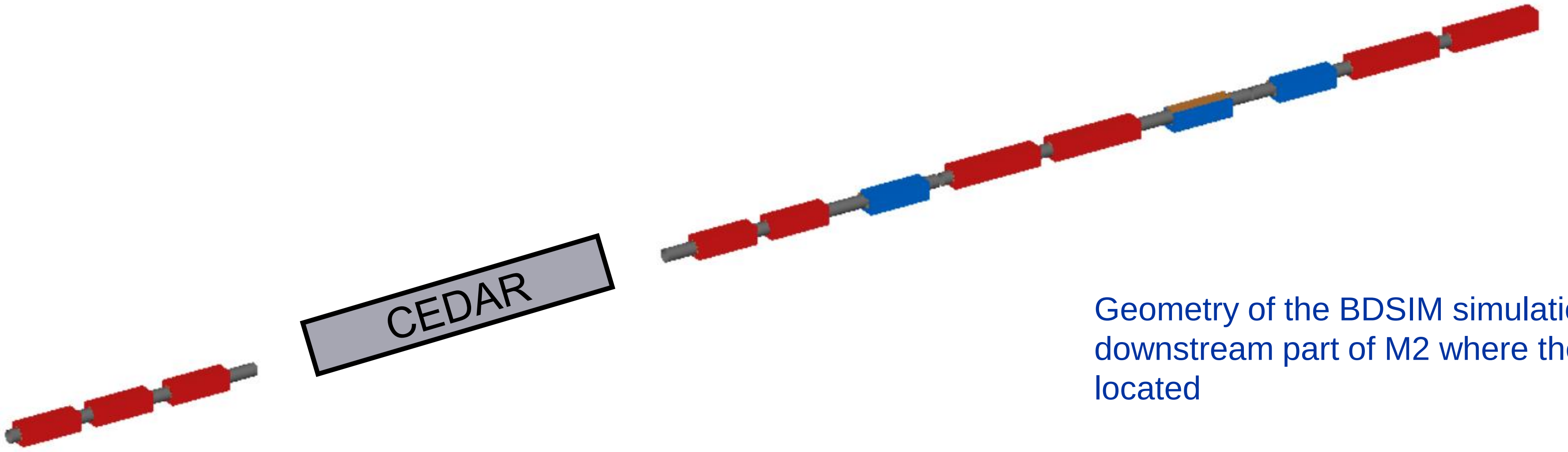


Optimising the conventional hadron beam

Multiple Scattering due to air

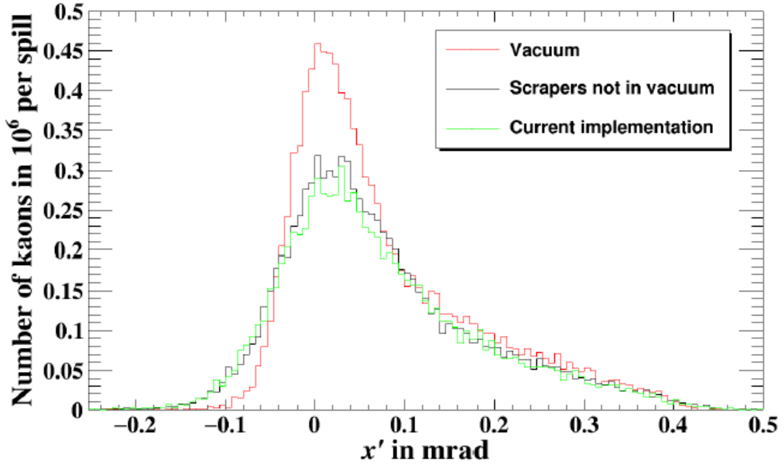
Current situation

- Currently there is about 80 m air along the beamline including nine Scrapers which are magnetic collimators where vacuum integration is costly and challenging.
- The sections in air add about 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 including the vacuum interruptions from the beam instrumentations.
- The secondary beam was taken from particle production of protons on target.

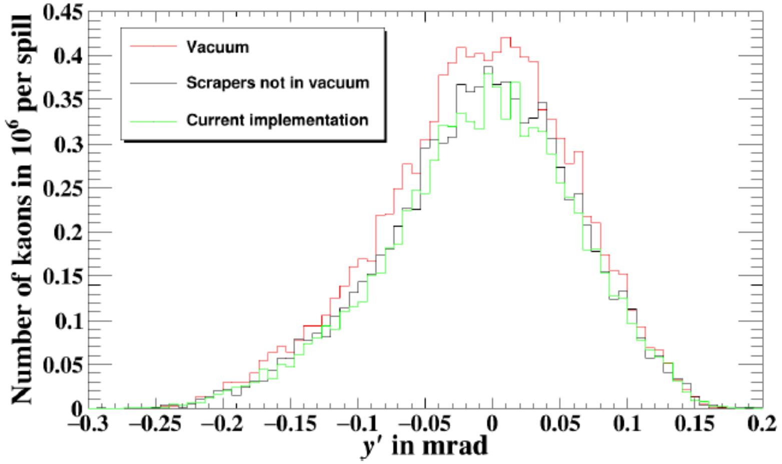


Geometry of the BDSIM simulation showing the downstream part of M2 where the CEDARs are located

Results from BDSIM simulation



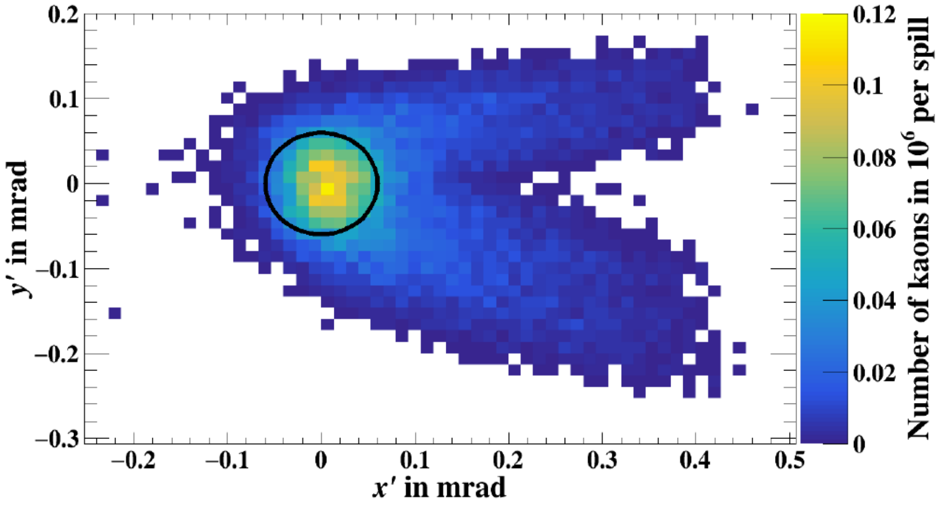
$\sigma_{x'}$ = 102.5 μrad, 109.3 μrad, 110.3 μrad



$\sigma_{y'}$ = 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%.



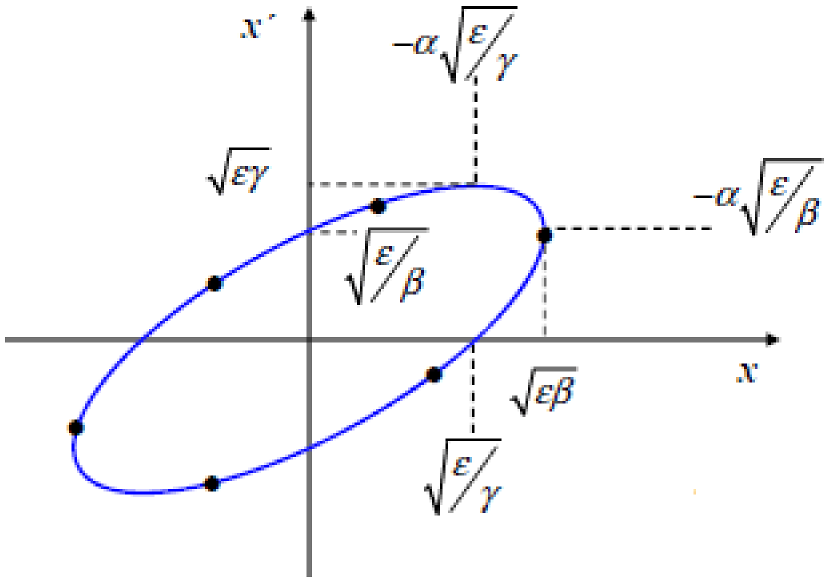
- For a particle to be tagged at the CEDARs **r’ =** $\sqrt{x'^2 + y'^2} \leq$ **60 μrad**
- Current implementation ~ 2.7 x 10^6 kaons per spill
- Scrapes not in vacuum ~ 3 x 10^6 kaons per spill → 11% improvement
- Full vacuum ~ 4 x 10^6 kaons per spill → 48% improvement

Optimising the conventional hadron beam

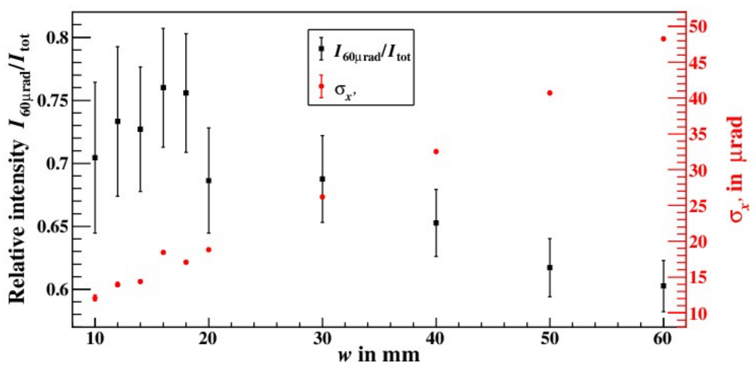
Beam Optics

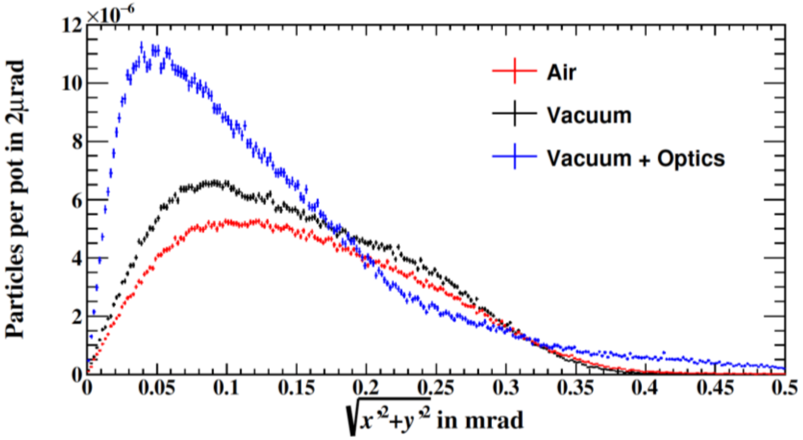
Improvements to the divergence

- The phase space (x’-x/y’-y) of the beam is constant, improving divergence means always having a 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

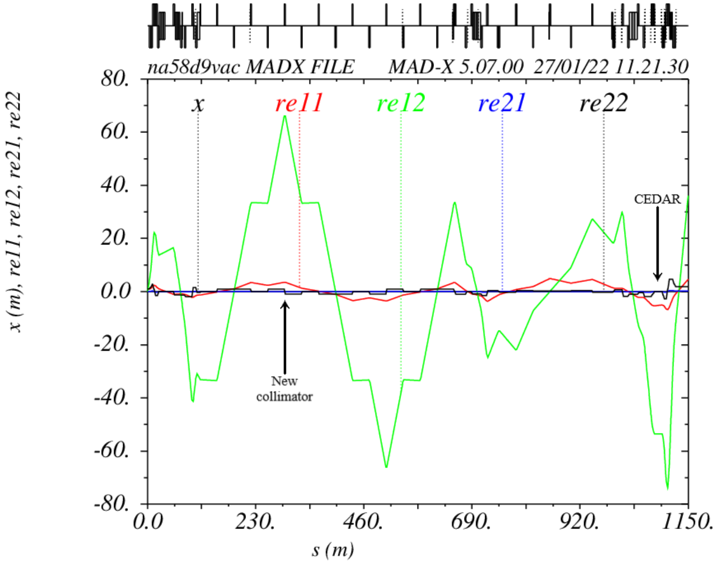


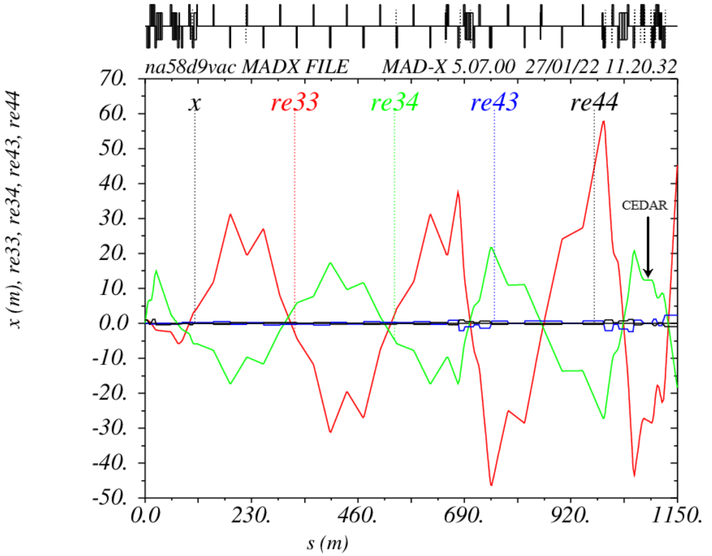


- The collimator is placed at a location with large horizontal beam size.
- By closing the collimators from 30 mm to 15 mm, divergence decreases by 50% and therefore the relative intensity within 60µrad increases.
- Vertical collimation shows small improvement as M2 is a vertically bending beam line 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

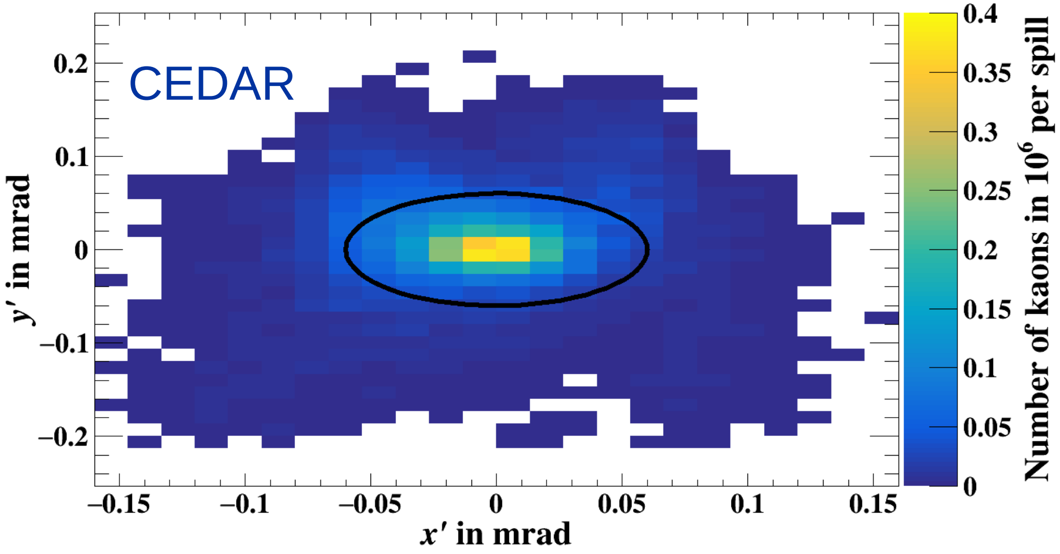
$$\mathbf{r'} = \sqrt{x'^2 + y'^2}$$

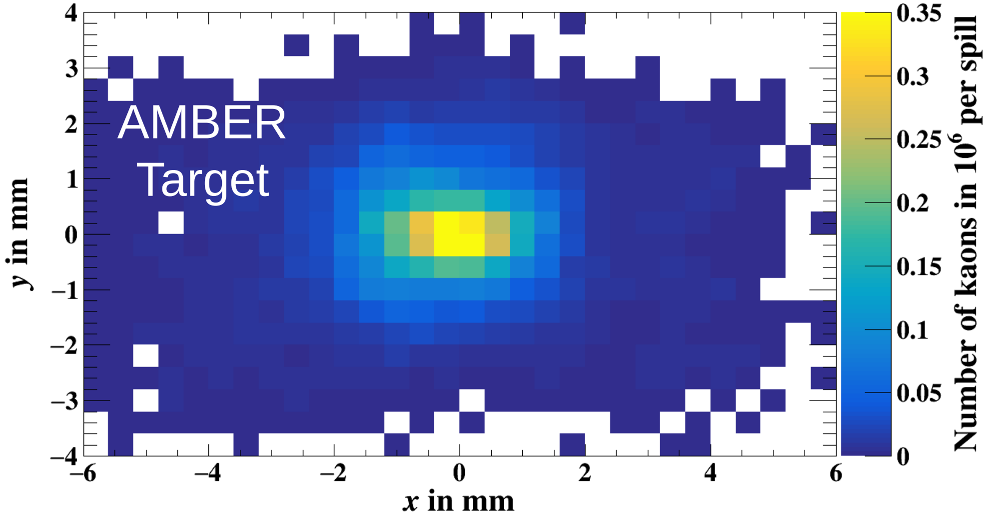
- For the vertical plane it is possible to decrease the divergence to $\sigma_{y'}$= 53 µrad by increasing the beam size at the CEDARs.





Results from the divergence improvement





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

  6×10^6 kaons per spill within 60 µrad

  (from 2.7×10^6 in the current scenario)
- This is for about 10^9 hadrons per spill and 120 units on the T6 target.
- Up to 150 units on T6 target possible and better collimation can lead to better relative intensity within 60 µrad.
- Focussing of the beam at the AMBER target has also been checked

  σ_x= 1.4 mm σ_y= 1 mm

M. Lino Diogo Dos Santos

CEDAR refurbishment YETS 2023/2024

The CEDAR open issues were compiled and reported at the end of the 2023 run. The two M2 CEDARs have been prioritized and refurbished:

Courtesy: K. Bernhard-Novotny

M2 - SPXCEDN001 - CR000002
M2 - SPXCEDN001- CR0000020

- Diaphragm – Mechanics Refurbishment
- Motor + Switches – Replacement
- Gas – Gas pipes refurbishment (correct sized shape etc.)
- Joints – Replacement
- Optics – Alignment
- XY Table – Table precision check / replacement
- Alignment – Realignment of CEDAR

For all CEDARS

- Installing new pressure sensors
- Validating new diaphragm movement algorithm
- Measuring quantum efficiency of spare PMTs – To requalify or discard the spare park of PMTs

Conclusions

- The M2 beamline is a unique facility delivering high-intensity, high-momenta muon and hadron beams.
- In order to optimise the identifiable kaons in the hadron beam minimising beamline material and optics have been studied to improve the divergence at the CEDARs.
- 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.
- With full vacuum and optics improvement the kaon flux within the 60µrad improves to almost 6E6 per spill → To be validated with data.
- Shielding improvement to increase the number of accumulated hadrons/year and technical details for the vacuum implementation are included in C. Ahdida and M. Lino Diogo Dos Santos' talks.

Thank You.

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