Beam line developments: update

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Intense - ESR meeting

Intense
H2020 MSCA ITN
G.A. 858199

Contents

CMBL commissioning

HSC42

This year we had a water leak at HSC42: second sextupole along ΠE5 beamline. It can't be operated until next year, so we are running without it.

It doesn't seem to affect Mu3e. It did have an effect for MEG.

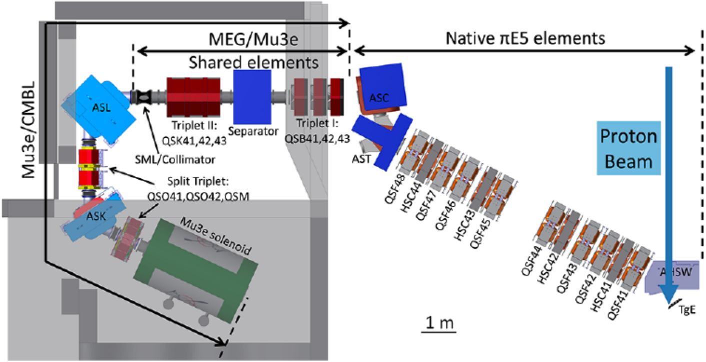
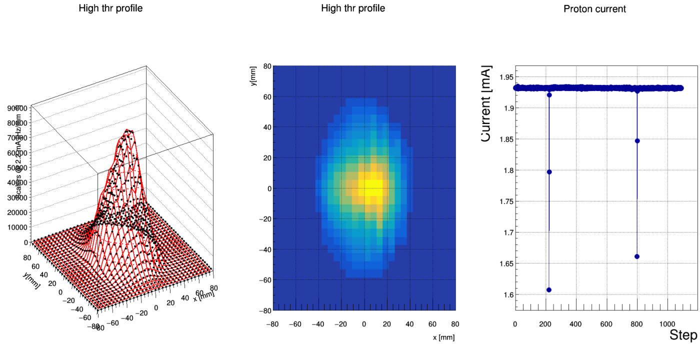


Figure: *Scanner position in red.*

Beam profile

We started from settings as obtained after 2019 campaign, obtaining 2.26 10^8 μ^+/s @ 2.2 mA. Last year we got to 1.93 10^8 μ^+/s @ 2.2 mA.



Spline xMPV = 6.64 mm, xMPV_STD = 18.57 mm
Spline yMPV = 2.10 mm, yMPV_STD = 20.66 mm
Spline ρ = 0.026
x = 0.87 mm, xSTD = 18.22 mm
y = 1.42 mm, ySTD = 23.20 mm
ρ = 0.083
Spline rate: 2.26e+08 μ^+/s @ 2.2 mA

Figure: *Final settings beam profile at collimator*

Phase space: quadrupole scan

We performed a scan on the QSK43 magnet, the last before the collimator, to extrapolate the phase space: for each value of the quadrupole current we measure the beam profile and the horizontal and vertical sigmas can be fitted to phase space parameters.

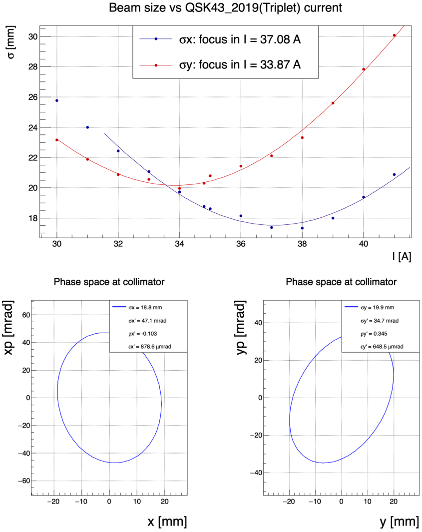
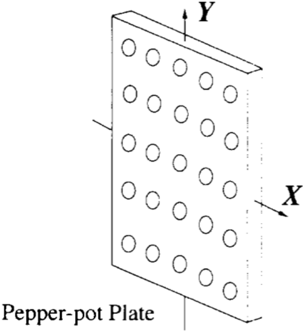
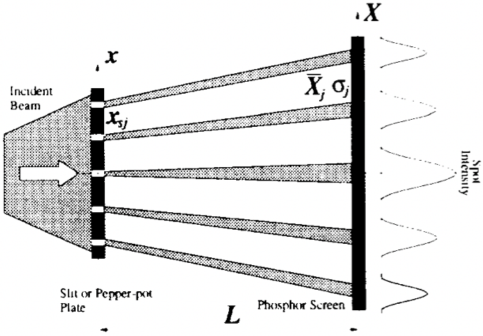


Figure: *QSK43 scan*

Pepper-pot measurement

It is a standard phase space measurement at proton and electron facilities up to 100 MeV in kinetic energy. The idea is to use a collimator with many holes in a drift space to measure at a certain distance the beam profile. Each beam spot has a size that is proportional to the divergence at collimator in the corresponding hole through the distance from the detector.

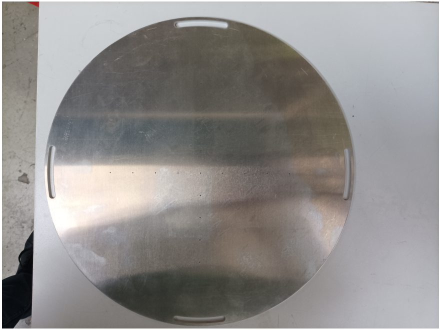


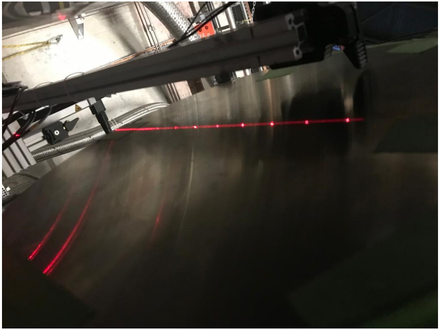


As soon as the separation among the spots is good, this measurement does not need any assumption on the beam structure: it is a direct measurement of the phase space. It is independent on alignment.

Phase space: pepper-pot measurement

The phase space measurement based on quadrupole scan is dependent on the assumption that the phase space is gaussian, but that is not completely true in our case. We performed a first pepper-pot measurement to get an estimate which is not dependent on the phase space itself. Moreover this measurement doesn't depend on the quadrupole strength either, so it is in principle a good way of checking whether the current modeling of our quadrupoles is correct.





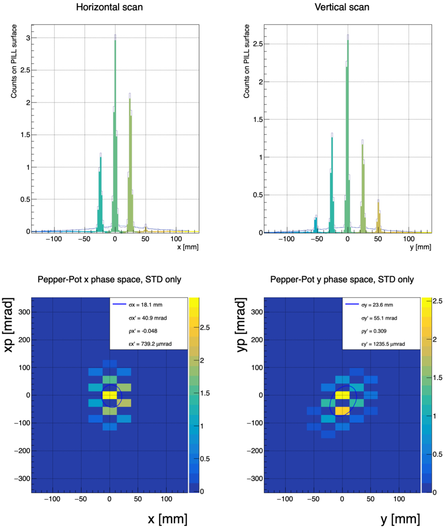
The idea is to collimate the beam through a grid of points and the size of the spots at the screen are proportional to the divergence at the grid location.

Phase space: pepper-pot measurement

Our pepper-pot grid is a cross of holes 25-mm apart on a 3-mm thick aluminum plate. Each hole has a 1-mm diameter.
The bkg subtraction was not good enough.

We then prepared new grids for the MEG II beam tuning time:

- blind flange: no holes
- staggered flange: same pattern staggered by 12.5 mm
- combined flange: hole pattern with finer mesh of 12.5 mm



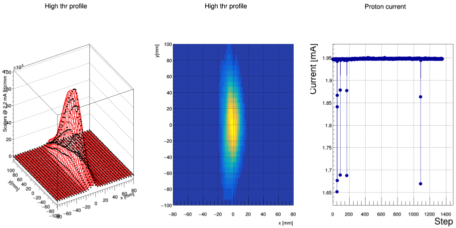
Beam profile

Last year our main issue was coupling into QSO41 with a straight beam. This year we aligned the centroid by iteratively tuning ASK41 and ASL41 keeping QSM41 fixed. Thanks to this approach we managed to get the beam aligned through the whole CMBL.

Increasing collimator aperture and keeping SEP41 at ± 180 kV we don't observe contamination and we get to 1.65 10^8 μ/s @ 2.2 mA.
Compared to last year:

- **2021:** 1.1 10^8 μ^+/s @ 2.2 mA, 57 % transmission to QSM
- **2022:** 1.65 10^8 μ^+/s @ 2.2 mA, 73 % transmission to QSM

+ increase by 17 % in rate at collimator.



Spline xMPV = -0.23 mm, xMPV_STD = 7.11 mm
Spline yMPV = -8.43 mm, yMPV_STD = 24.35 mm
Spline ρ = -0.048
x = -1.83 mm, xSTD = 8.24 mm
y = -2.39 mm, ySTD = 36.70 mm
ρ = 0.026
Spline rate: 1.65e+08 μ^+/s @ 2.2 mA

Figure: *Focused beam profile, SEP41 at 180 kV with inner collimator removed.*

Mu3e scanner

Measurements at solenoid center are performed using an Avalanche PhotoDiode (APD), moved by two piezoelectric motors with optical encoders. The whole scanner was built by Ioannis. This year we ran with a MIDAS front-end.

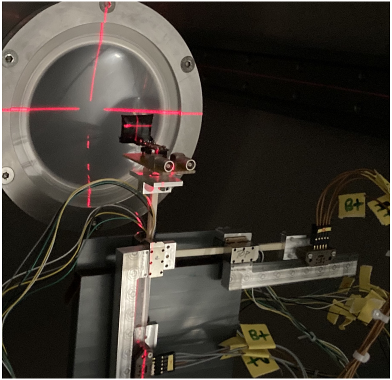
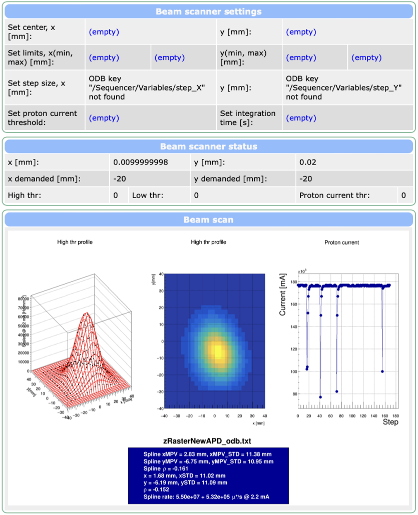


Figure: *APD detector.*



Beam scanner settings

Set center, x [mm]:	(empty)		y [mm]:	(empty)	
Set limits, x(min, max) [mm]:	(empty)	(empty)	y(min, max) [mm]:	(empty)	(empty)
Set step size, x [mm]:	ODB key "/Sequencer/Variables/step_X" not found		y [mm]:	ODB key "/Sequencer/Variables/step_Y" not found	
Set proton current threshold:	(empty)		Set integration time [s]:	(empty)	

Beam scanner status

x [mm]:	0.0099999998		y [mm]:	0.02	
x demanded [mm]:	-20		y demanded [mm]:	-20	
High thr:	0	Low thr:	0	Proton current thr:	0

Beam scan

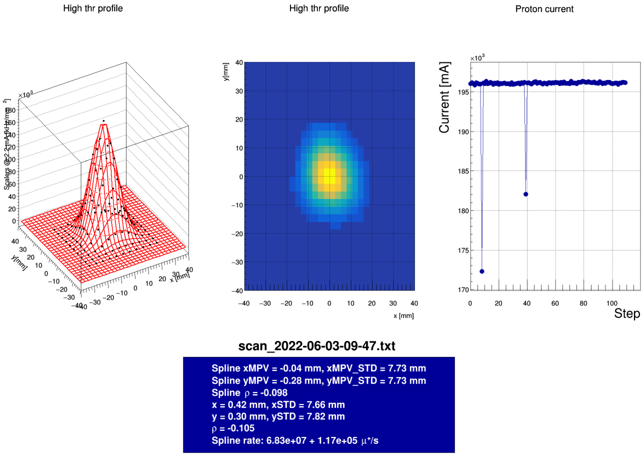
zRasterNewAPD_odb.txt

Spline xMPV = 2.83 mm, xMPV_STD = 11.38 mm
Spline yMPV = -6.75 mm, yMPV_STD = 10.95 mm
Spline ρ = -0.161
x = 1.68 mm, xSTD = 11.02 mm
y = -6.19 mm, ySTD = 11.09 mm
ρ = -0.152
Spline rate: 5.50e+07 + 5.32e+05 μ^+/s @ 2.2 mA

Figure: *MIDAS front-end.*

Beam profile

Transmission to the solenoid center is limited by the 60 mm beam pipe (-44 %) and by the 40 mm window (-27 % w.r.t. 60 mm beam pipe configuration) at the end, leading to an overall 59 % loss in transmission. w.r.t. QSM41.



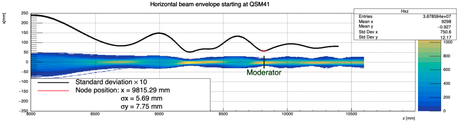
Spline xMPV = -0.04 mm, xMPV_STD = 7.73 mm
Spline yMPV = -0.28 mm, yMPV_STD = 7.73 mm
Spline ρ = -0.098
x = 0.42 mm, xSTD = 7.66 mm
y = 0.30 mm, ySTD = 7.82 mm
ρ = -0.105
Spline rate: 6.83e+07 + 1.17e+05 μ^+/s

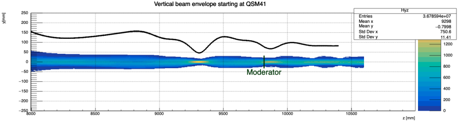
Figure: *Beam profile at Mu3e center*

Beam profile: solenoid field studies

Increasing the solenoid field we obtain an increase in transmission. This is probably due to the position of the beam nodes along the center line. As an example you see a simulation with last year's phase space at QSM as an input.

By varying the magnetic field we are moving the nodes probably allowing for better transmission through the window. This will need further studies to be confirmed.





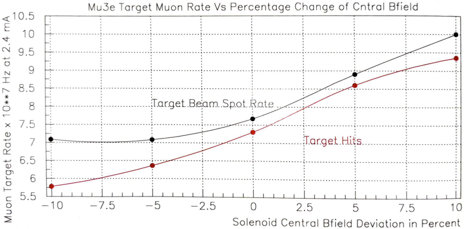


Figure: *The red line is obtained by integrating the rate for r < 19 mm.*

Beam settings

Here we show the rates as a function of the measurement condition

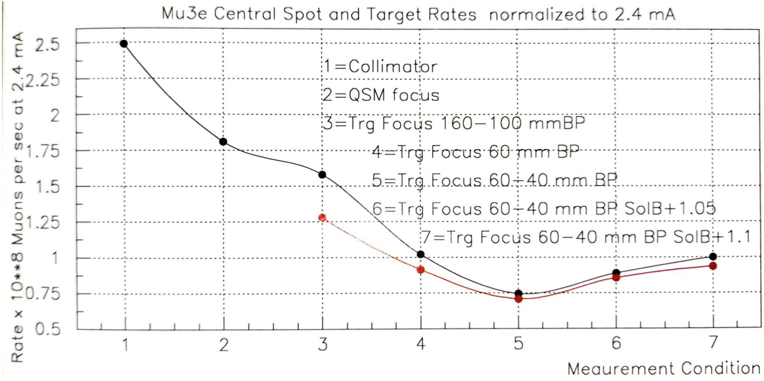


Figure: *The red line is obtained by integrating the rate for r < 19 mm.*

Conclusion

Beam Commissioning Comparison

Rates	Collimator	QSM41	Mu3e
2021	$2.11\ 10^8\ \mu^+/s$	$1.2\ 10^8\ \mu^+/s$	$4.76\ 10^7\ \mu^+/s$
2022	$2.47\ 10^8\ \mu^+/s$	$1.8\ 10^8\ \mu^+/s$	$7.46\ 10^7\ \mu^+/s$

Table: All rates are normalised to 2.4 mA.

Mu3e 2022 Commissioning Results

Rates	Collimator	QSM41	Mu3e	Mu3e + 5%	Mu3e + 10%
2022	$2.47\ 10^8\ \mu^+/s$	$1.8\ 10^8\ \mu^+/s$	$7.46\ 10^7\ \mu^+/s$	$8.84\ 10^7\ \mu^+/s$	$1.1\ 10^8\ \mu^+/s$
2022 on target	-	-	$7.1\ 10^7\ \mu^+/s$	$8.52\ 10^7\ \mu^+/s$	$9.35\ 10^7\ \mu^+/s$

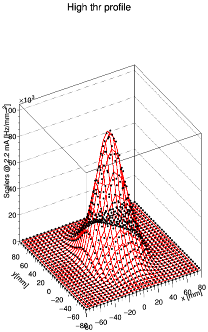
Table: All rates are normalised to 2.4 mA.

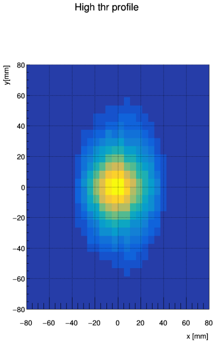
- Transmission from collimator to QSM has been increased w.r.t. last year from 57 % (2021) to 73 % (2022)
- Increasing the field in the solenoid improves the transmission through the 40 mm window right before the target from 42 % to 50 %. We'll work to assess precisely the source of this inefficiency.
- The commissioning was succesfully, but the beamline itself was not completely functional: due to a water leak for 2022 it is not possible to power HSC42, one of the sextupoles along the beamline. We didn't see differences in the beam behaviour, but we will need to confirm the results from this year's campaign next year.

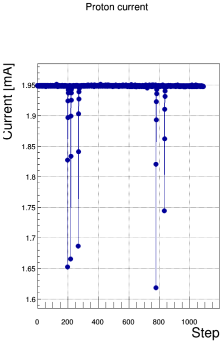
MEG II beam tuning

Collimator focus

We started testing again Mu3e settings at collimator. No major differences w.r.t. in beam profile: drop of intensity by 10 %. This is probably due to moving upstream the collimator by 20 cm to accommodate SciFi's flange.





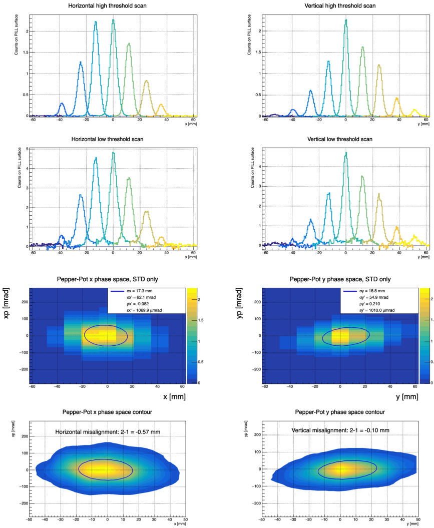


Spline xMPV = -0.82 mm, xMPV_STD = 17.25 mm
Spline yMPV = -1.81 mm, yMPV_STD = 19.47 mm
Spline ρ = 0.011
x = 1.39 mm, xSTD = 17.33 mm
y = 0.37 mm, ySTD = 22.07 mm
ρ = -0.041
Spline rate: 2.05e+08 μ^+/s @ 2.2 mA

Phase space: pepper-pot measurement

We combined the scans with the normal, blind and staggered plate to obtain a phase space measurement independent on magnet's strength.

Not easy to compare with the quadrupole scan right away as it assumes gaussian fits, while in this case it might not be a good approximation.
→ we'll need to propagate this phase space with the settings of the quadrupole scan and then compare the results.


Horizontal high threshold scan

Vertical high threshold scan

Horizontal low threshold scan

Vertical low threshold scan

Pepper-Pot x phase space, STD only

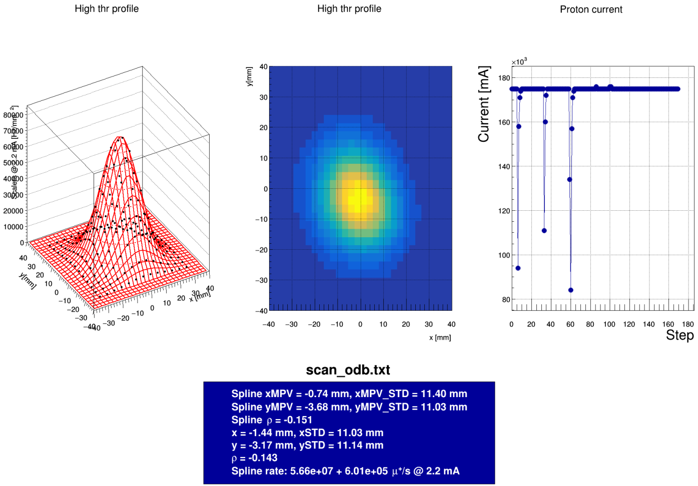
Pepper-Pot y phase space, STD only

Pepper-Pot x phase space contour

Pepper-Pot y phase space contour

COBRA center focus

We noticed a severe decrease in transmission efficiency at CC w.r.t. to last year: we needed to tune the sextupoles to get back to usual transmission.



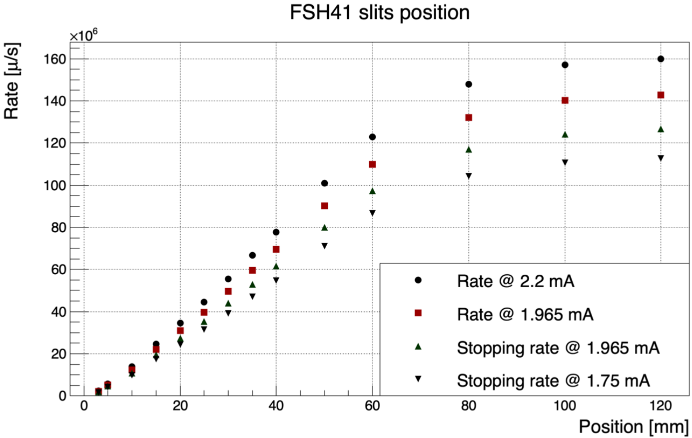
Spline xMPV = -0.74 mm, xMPV_STD = 11.40 mm
Spline yMPV = -3.68 mm, yMPV_STD = 11.03 mm
Spline ρ = -0.151
x = -1.44 mm, xSTD = 11.03 mm
y = -3.17 mm, ySTD = 11.14 mm
ρ = -0.143
Spline rate: 5.66e+07 + 6.01e+05 μ^+/s @ 2.2 mA

Figure: *Final settings beam profile at CC. Slits settings for MEG II physics run.*

Slits

The chosen operation rates are:

- MEGII low: FSH41 = 22.5 mm → $3 \times 10^7\ \mu^+$/s
- MEGII high: FSH41 = 30 mm → $5 \times 10^7\ \mu^+$/s



Detector intercalibration

We performed a measurement of the pTC and LXe response as a function of the beam rate.

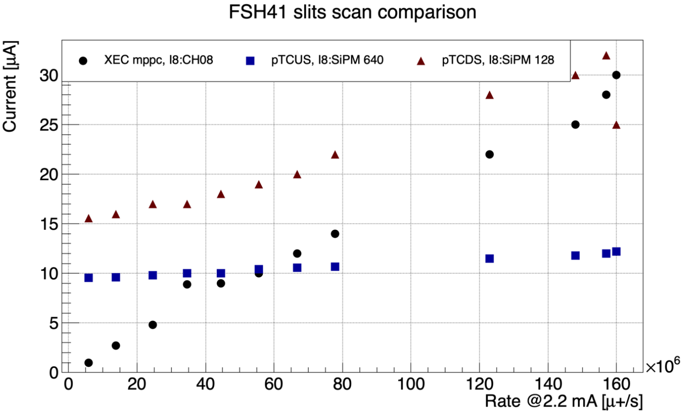
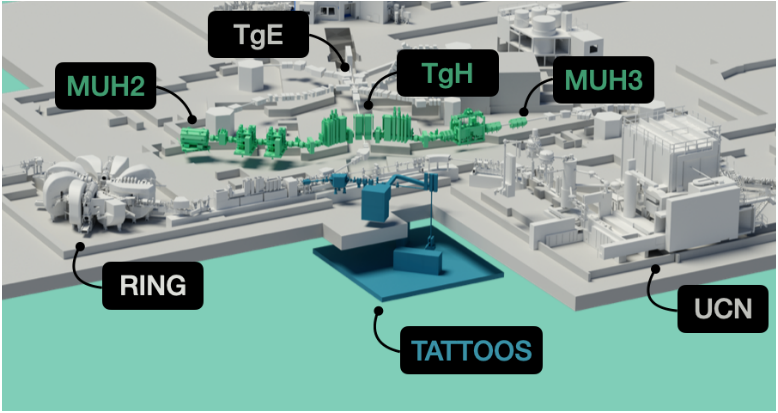


Figure: *Final settings beam profile at CC. Slits settings for MEG II physics run.*

MUH2 optimization



MUH2 new layout

We have a new layout of MUH2 based on input from techniciancs including two short separators and an upgraded version of the capture solenoids, with he possibility to singularly energize three pancakes of coils inside them. I'm currently exploring the parameter space to find highest intensity setting for different momentum bites.

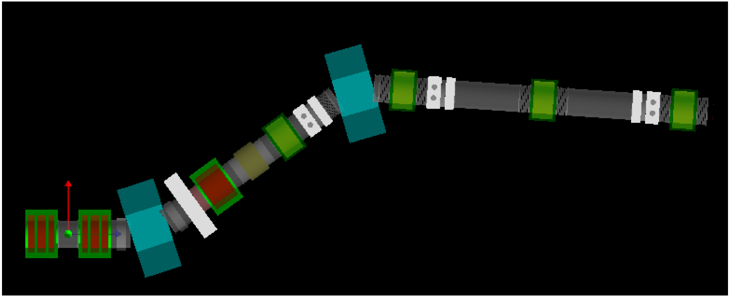


Figure: *New MUH2 layout.*

A Bayesian optimization on rate only is performed to explore the parameter space. Then a Genetic Algorithm is used to optimize contemporary rate, beam spot size and momentum spread.

MUH2 optimization

We have a new layout of MUH2. I'm currently exploring the parameter space to find highest intensity setting for different momentum bites.

At the moment we don't have yet the limits in current of all the element, so this search has soft boundaries on the beamline parameters.

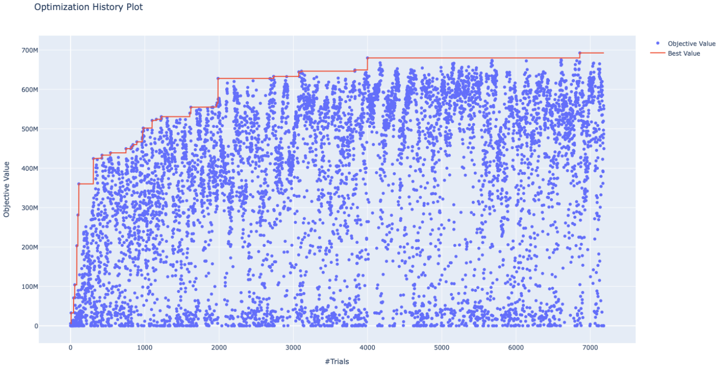
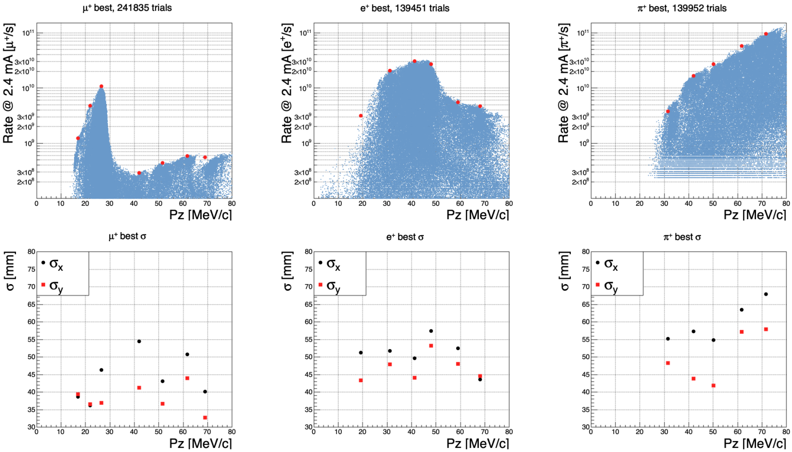
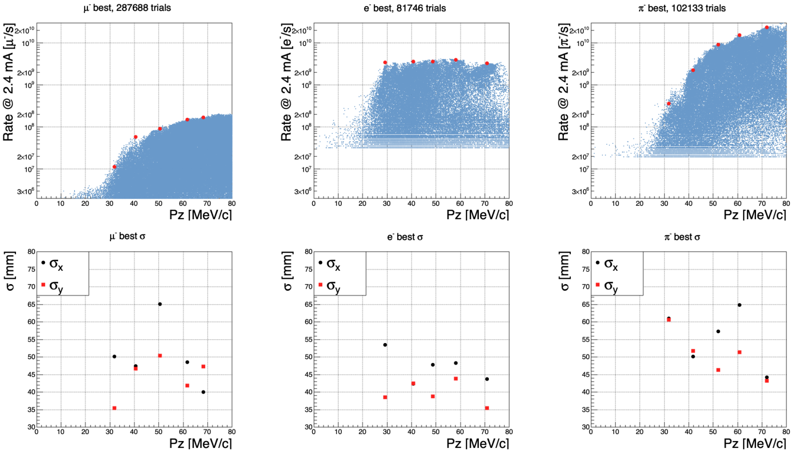


Figure: *Optimization progress with iteration number. The objective value is the beam rate in* μ^+*/s. The beam is cut between 60 and 80 MeV/c.*

Best trials: positive particles



Best trials: negative particles



Next steps

- run optimization with realistic field map of graded field capture solenoid
- study slits system exploitability inside dipole
- working on an NN surrogate model to speed-up optimization