Beam simulation efforts - short summary

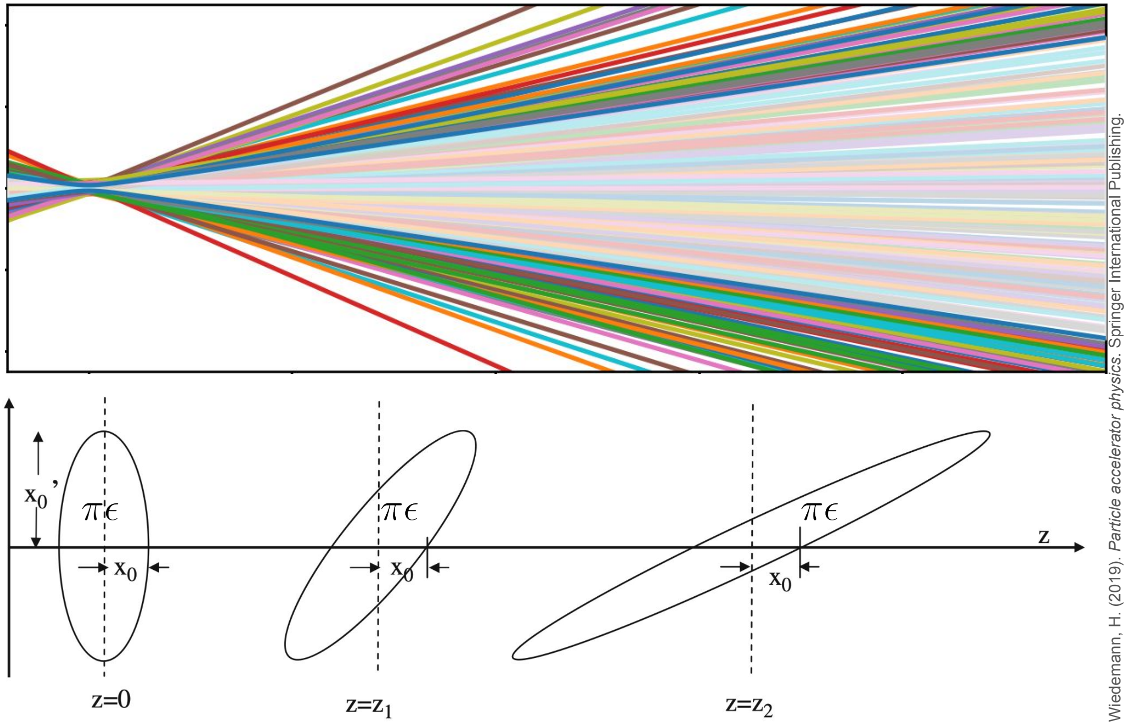
Implementation of a gaussian beam

Gaussian beam:

- Particle positions and momenta at all z are gaussian distributed

Implementation:

- Set two parameters per dimension to fix shape of the beam (emittance, initial/ focus beam width, momentum spread)
- Generate particle x & x' (y & y') that follow expected distribution at specific z_0

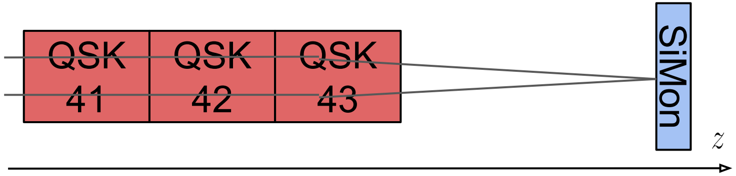


Wiedemann, H. (2019). *Particle accelerator physics*. Springer International Publishing.

PiE5 phase space analysis

Quadrupole scan:

- Vary the current in a magnet to change focus distance
- Record beam width at fixed z
- Use beam transport matrix formalism to extract full set of Twiss parameters

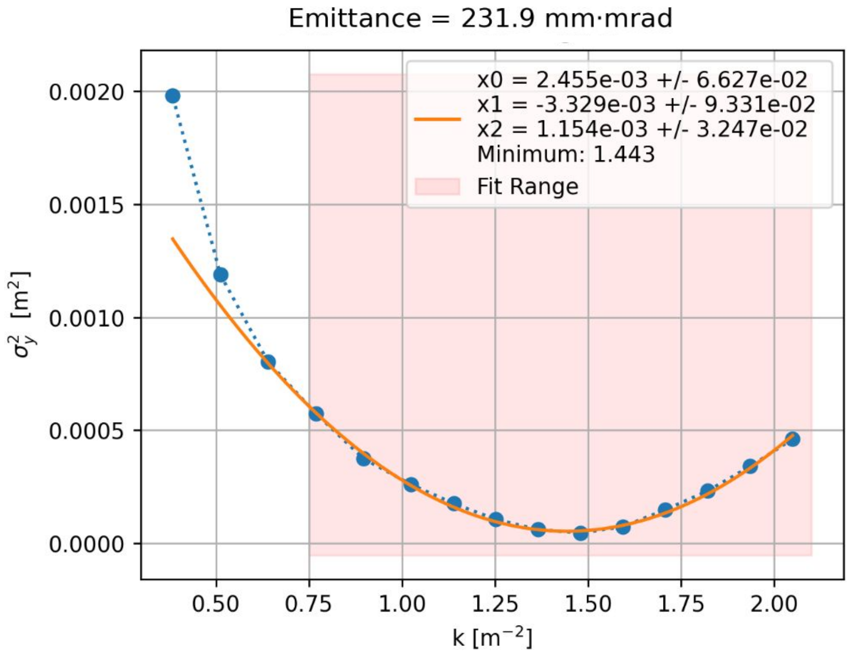


Result:

πE5 pion beam, 65 MeV/c

- Vertical: $\epsilon \simeq 209 - 232 \text{ mm} \cdot \text{mrad}$
- Horizontal: $\epsilon \simeq 617 \text{ mm} \cdot \text{mrad}$

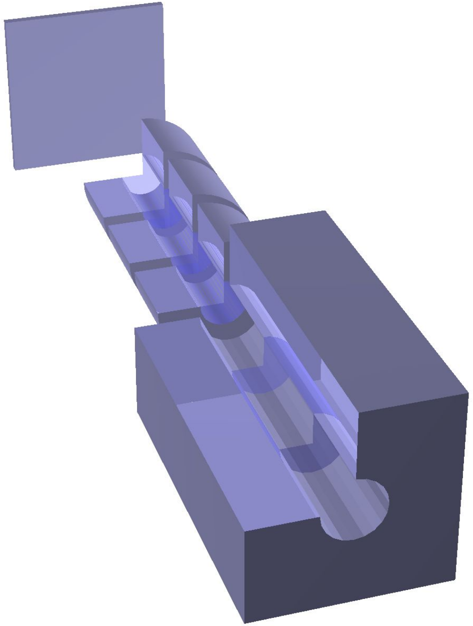
Example: QSK43 scan vertical



Implementation of upstream beam elements

Multiple upstream elements of beamline have been implemented:

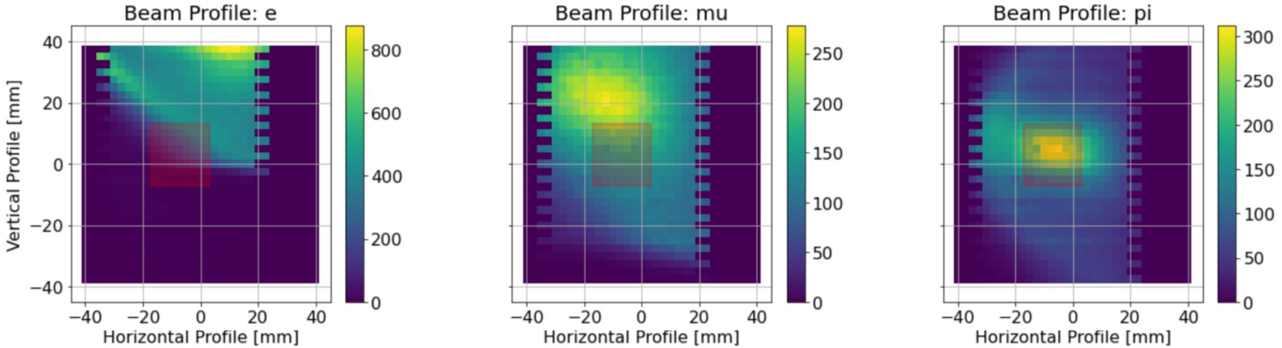
- **Quadrupole magnets**
  - Based on geometry of QSK 41 - 43 triplet
  - Quadrupole field strength can be set in json file
  - Field can be scaled in macro file
- **Separator**
  - Based on geometry of SEP 41
  - Strength of electric and magnetic field can be set in json file
- **Collimator**
  - Thickness and opening in x & y can be set in json file
- **Ghost planes**
  - Record the particles that fly through
- (Dipole magnets)
  - Under construction



Comparison with last beam time results

Measurement:

- **Rate: 633 kH / 46 % in ATAR Box**
- Mean X = 0.3 mm
- Mean Y = 0.2 mm
- Sig X = 23 mm
- Sig Y = 10.1 mm



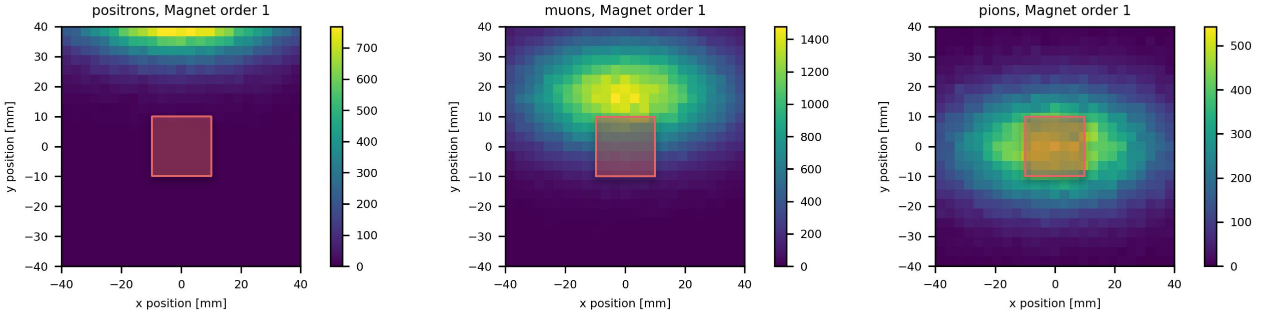
Simulation:

Pions:

- Mean X = 0.0 mm
- Mean Y = 0.0 mm
- Sig X = 26.76 mm
- Sig Y = 13.1 mm

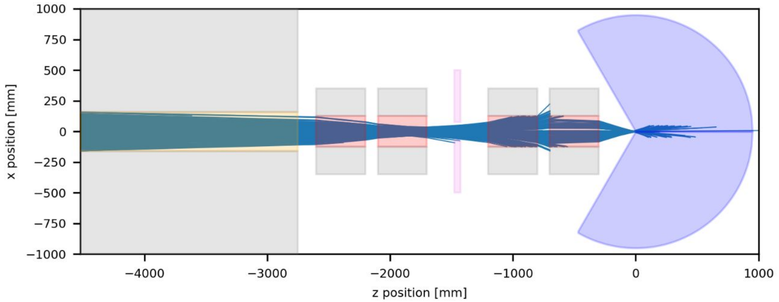
Muons:

- Mean Y = 17.4 mm



Full final beam section simulation - pure pion beam

Short beamline setup:



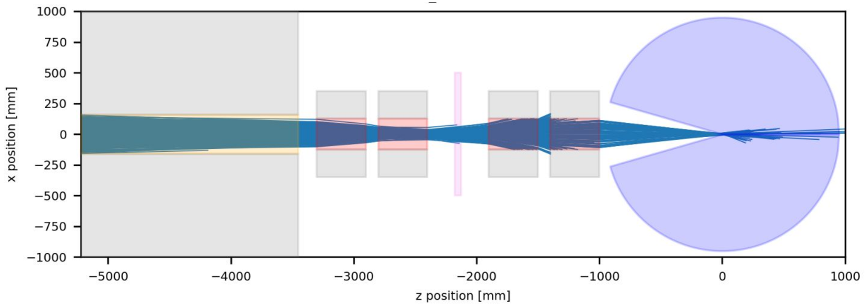
Arriving pions:

- **6.9 %** of simulated pions stop in ATAR
- **~ 372 kHz** estimated from beamtime rates

Backgrounds, per stopped pion:

- **0.03 pion** in Calo
- **0.33 muon** in Calo
- **0.013 muon** in ATAR

Long beamline setup:



Arriving pions:

- **4.1 %** of simulated pions stop in ATAR
- **~ 219 kHz** estimated from beamtime rates

Backgrounds, per stopped pion:

- **0.09 pion** in Calo
- **1.05 muon** in Calo
- **0.014 muon** in ATAR

Latest developments

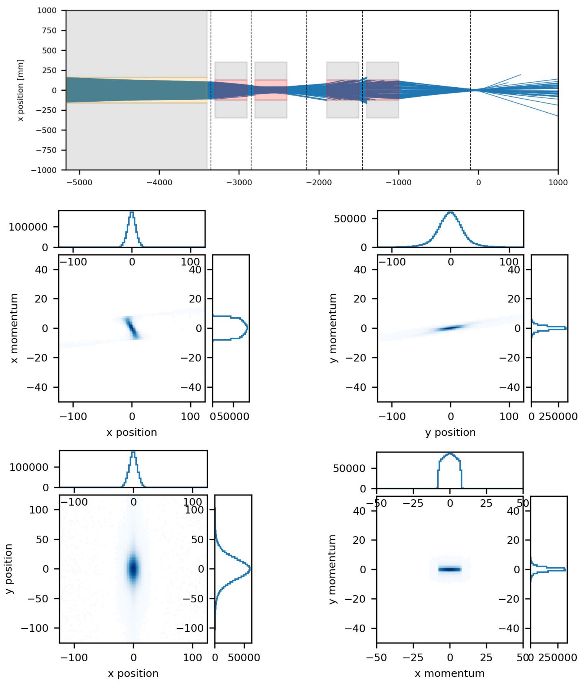
Near beam generator makes simulation easier and more efficient:

- Reduce distance from simulation starting point to target (New: 10 cm)
- Keep the particle distribution from full beamline simulation

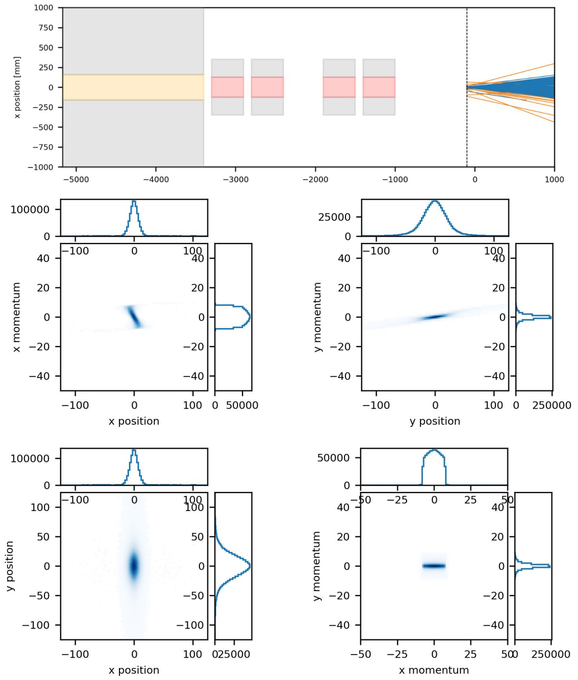
Previous setup:

- Less than 10% of pions reach detector

Full beamline simulation:

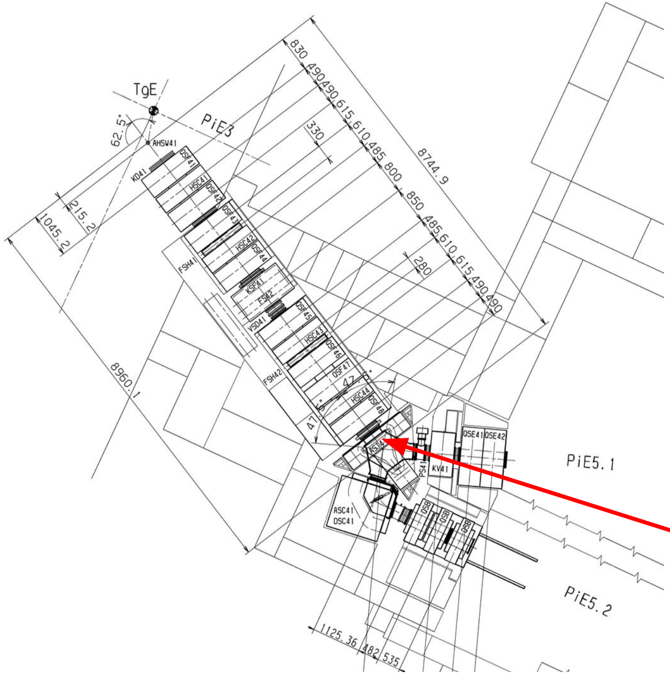


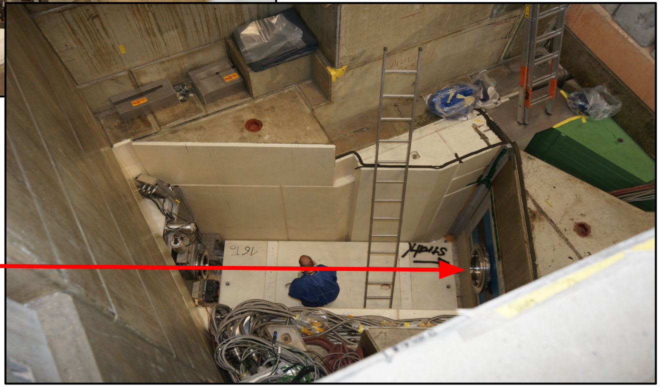
Near beam generator:



Latest developments

PiE5 beamline: Upstream degrader requires major intervention but is not impossible





possible location of a foil

Latest developments

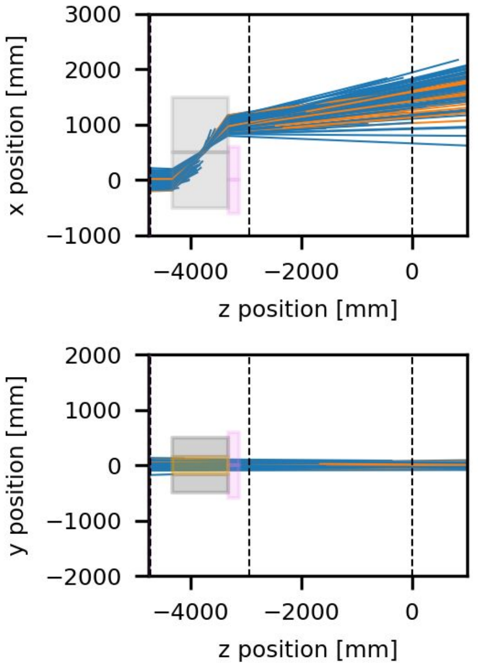
Upstream degrader:

- Introducing a momentum difference upstream of the dipole magnets improves separation between pions, muons and electrons

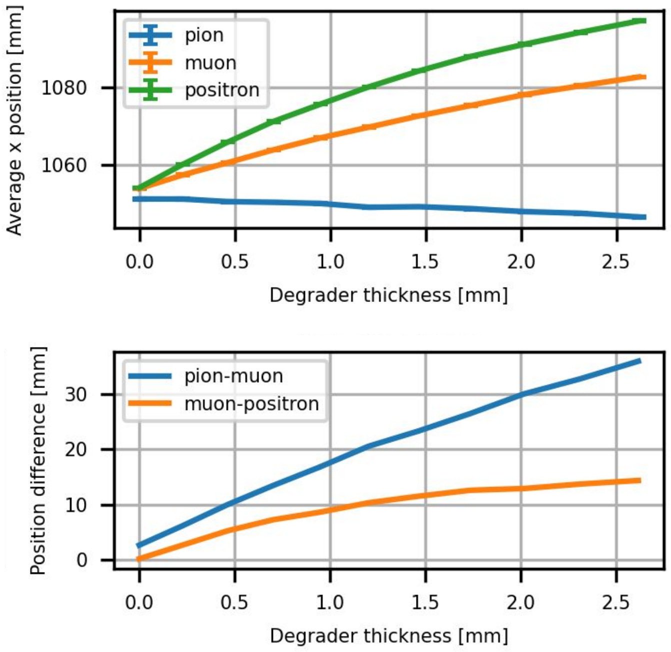
Sidenote:

- Introducing a degrader before the separator only helps selecting the light particles

Simplified geometry:



Separation:



Beam Transport with a Quadrupole

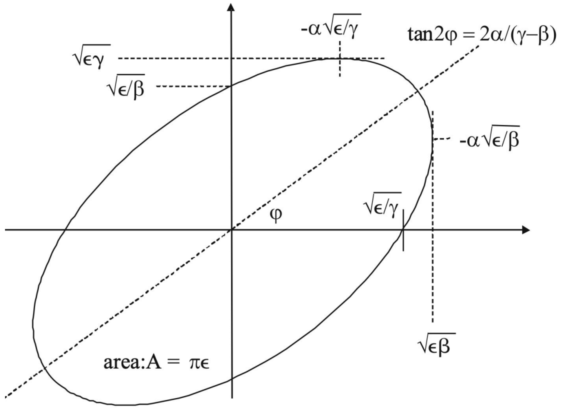
Define sigma Matrix:

$$\boldsymbol{\sigma} = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} = \epsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}$$

$$\sigma_{11} = \langle x_i^2 \rangle = \epsilon\beta,$$

$$\sigma_{22} = \langle x_i'^2 \rangle = \epsilon\gamma,$$

$$\sigma_{12} = \langle x_i x_i' \rangle = -\epsilon\alpha.$$



Sigma Matrix changes as:

$$\boldsymbol{\sigma}_1 = \mathcal{M}\boldsymbol{\sigma}_0\mathcal{M}^T$$

Free beam transport

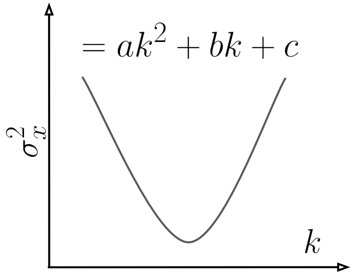
Focus

$$\mathcal{M} = \begin{pmatrix} 1-d/f & d \\ -1/f & 1 \end{pmatrix} = \begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix}$$

Sigma at new position:

$$\sigma_{1,11}(k) = \left(d^2\ell_q^2\sigma_{0,11}\right)k^2 + \left(-2d\,\ell_q\sigma_{0,11} - 2d^2\ell_q\sigma_{0,12}\right)k + \left(\sigma_{0,11} + 2d\,\sigma_{0,12} + d^2\sigma_{0,22}\right)$$

$$\sigma_{0,11} = \frac{a}{d^2\ell_q^2} \qquad \sigma_{0,12} = \frac{-b - 2d\ell_q\sigma_{0,11}}{2d^2\ell_q} \qquad \sigma_{0,22} = \frac{c - \sigma_{0,11} - 2d\sigma_{0,12}}{d^2}$$

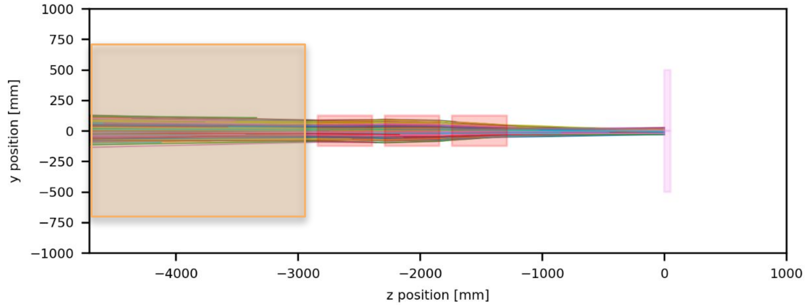


Emittance: $\sigma_{11}\,\sigma_{22} - \sigma_{12}^2 = \epsilon^2$

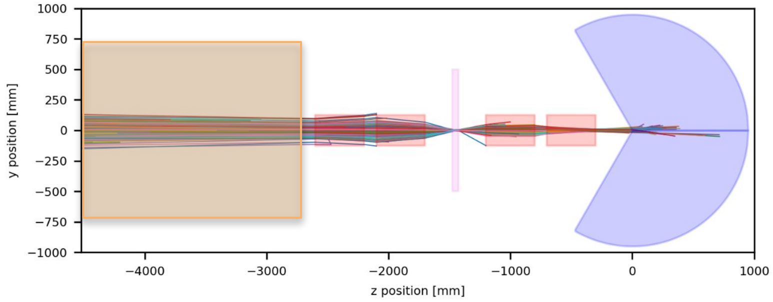
Short vs long focus

Example of scaling with measured rate:

Beamtime setup:



Short beamline setup:



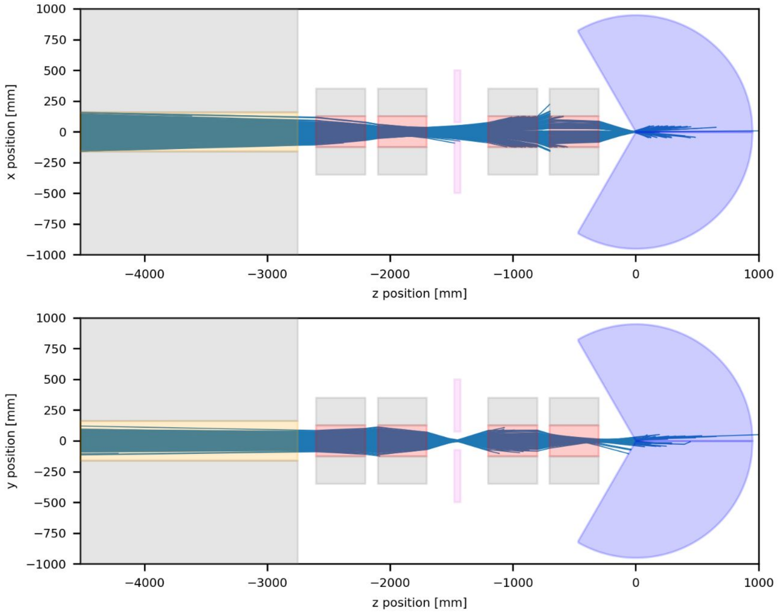
Counts: Pions on SiMON: 268’437 / 1’000’000 → Pions in ATAR: 69’425 / 1’000’000

Corresponds to ↕ Corresponds to ↕

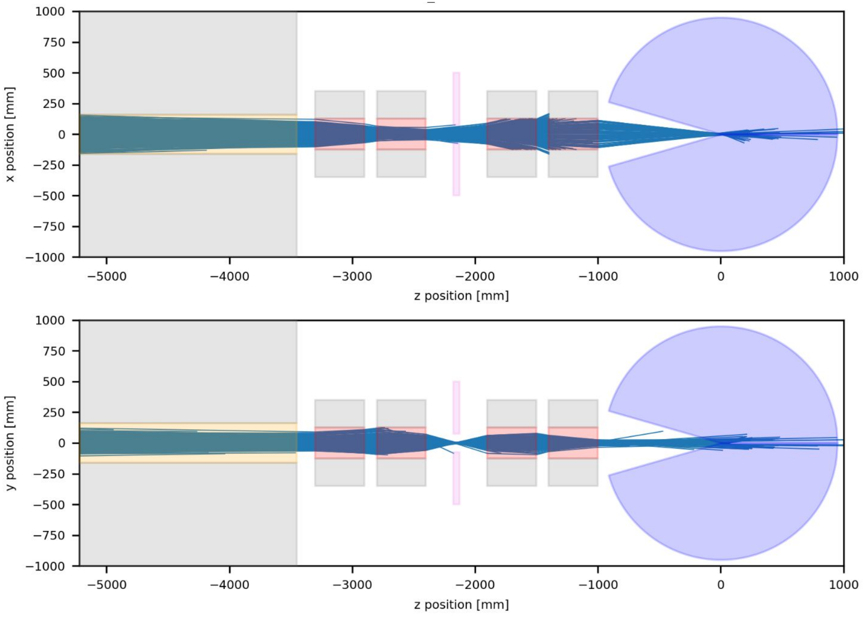
Rates: Measured: 1’375 kHz → Calculated: 372 kHz

Full final beam section simulation - pure pion beam

Short beamline setup:



Long beamline setup:

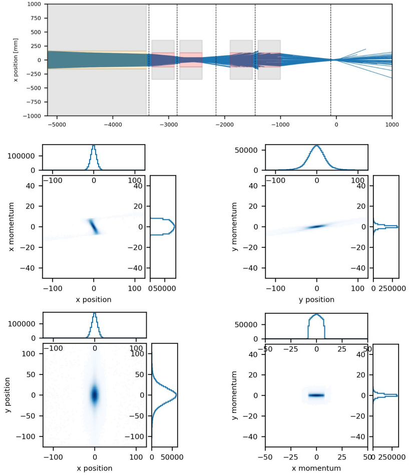


Latest developments

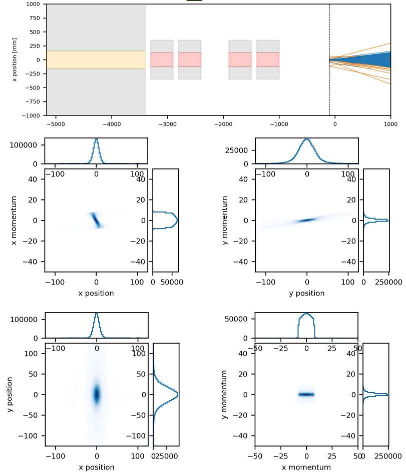
Near beam generator:

- Generate particles 10 cm before target to increase simulation efficiency
- Keep particle distribution from full simulation

Full simulation:



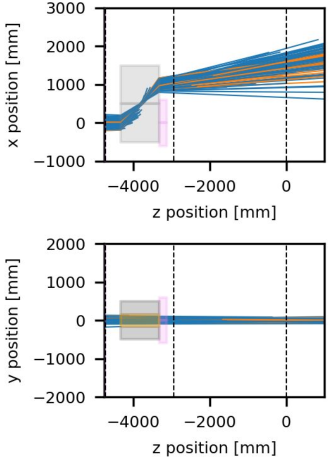
Near beam generator:



Investigate effect of upstream degrader:

- Introducing an upstream momentum difference improves separation between pions, muons and electrons

Geometry:



Separation: