PAUL SCHERRER INSTITUT

PSI

Cong Chen :: MIXE :: Paul Scherrer Institute & Institution of High Energy Physics

Muon beam line simulation for negative muons

Guided by Dr. Thomas Prokscha

Oct 16, 2023

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outline

1. The use of a beam of negative muons: MIXE
2. Current status of μE1
3. The parameters of elements in the simulation
4. Beam envelope calculation of μE1 with new layout

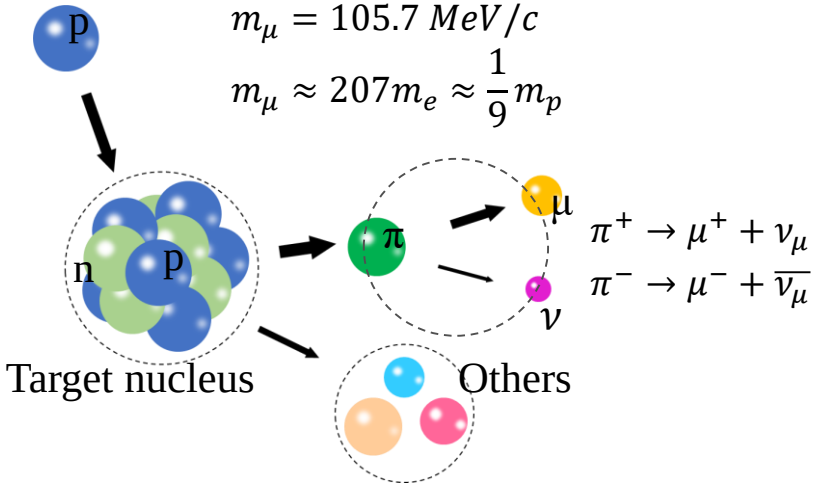
The use of a beam of negative muons: MIXE

negative muon:

- drived by proton accelerator
- easily captured
- heavy mass:

$$m_\mu = 105.7\ MeV/c$$

$$m_\mu \approx 207 m_e \approx \frac{1}{9} m_p$$

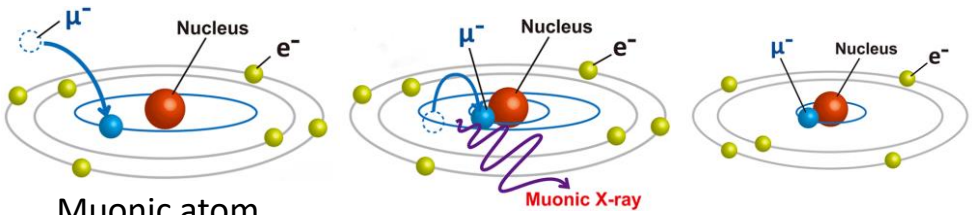


$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\pi^- \rightarrow \mu^- + \overline{\nu_\mu}$$

Muon Induced X-ray Emission (MIXE):

- probes for elemental composition
- non-destructive
- bulk matter & depth-resolve (Bragg profiles)
- light elemental sensitivity
- simultaneous multielement
- isotopic analysis

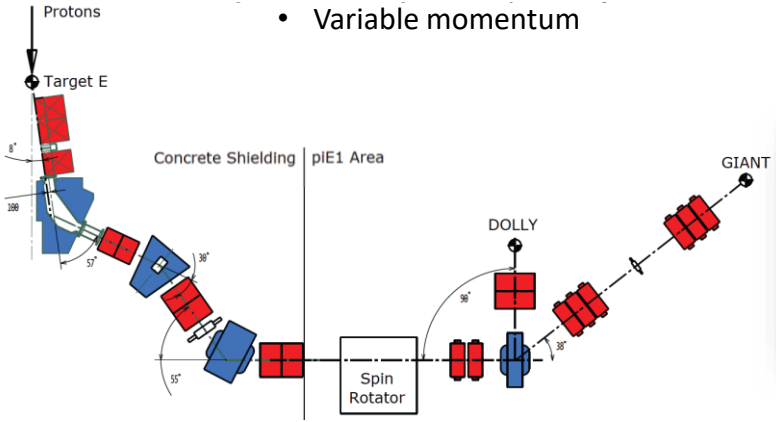


Muonic atom

The use of a beam of negative muons: MIXE

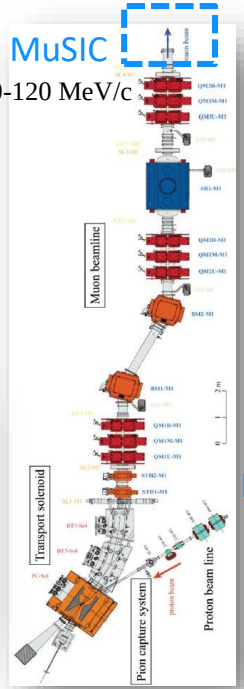
MIXE @PSI :

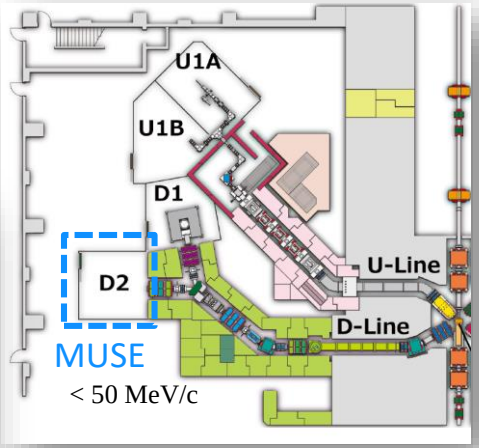
- **πE1, GIANT,**
- **some samples:**
  cultural heritage, battery, meteorites…
- **countious beam**
- Negative muons only available as “cloud” muons
- A plan for a **permanent** user station
  - Narrow momentum distribution
  - Variable momentum



MIXE @other facitities

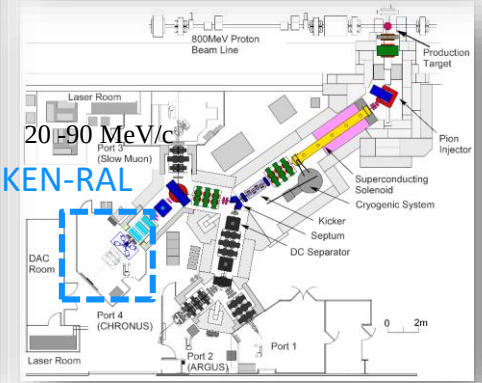
MuSIC
20-120 MeV/c



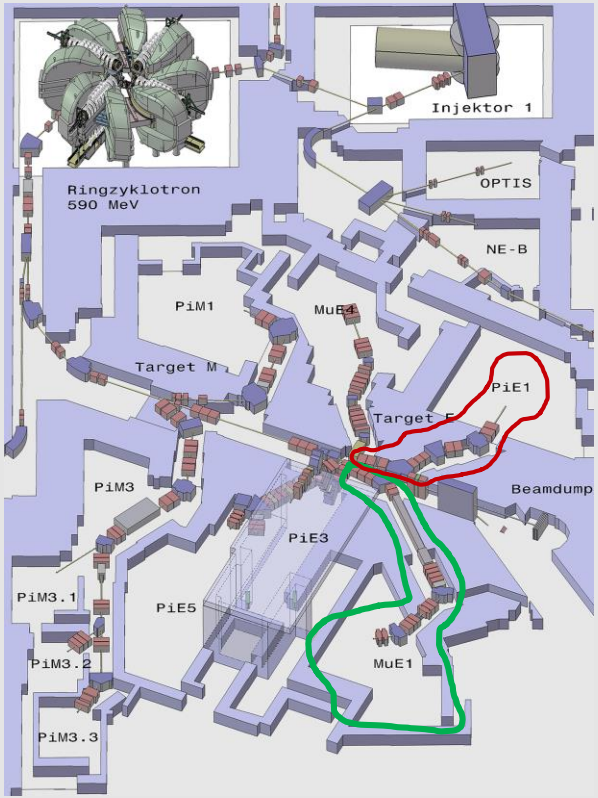


MUSE
< 50 MeV/c

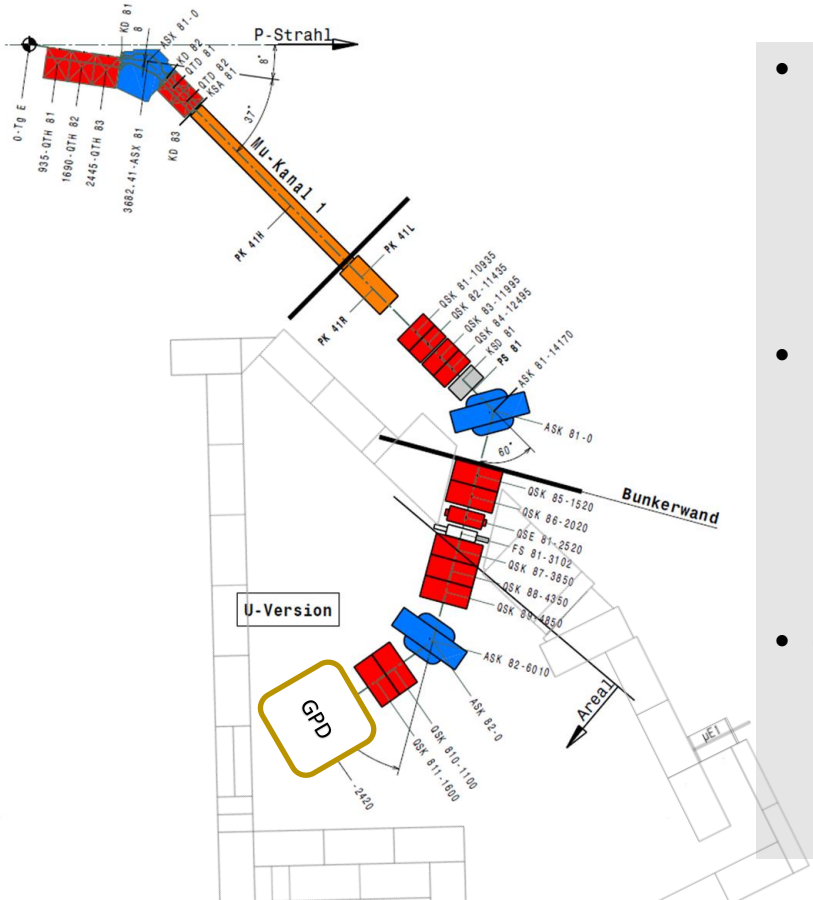
20-90 MeV/c
RIKEN-RAL



Current status of μE1



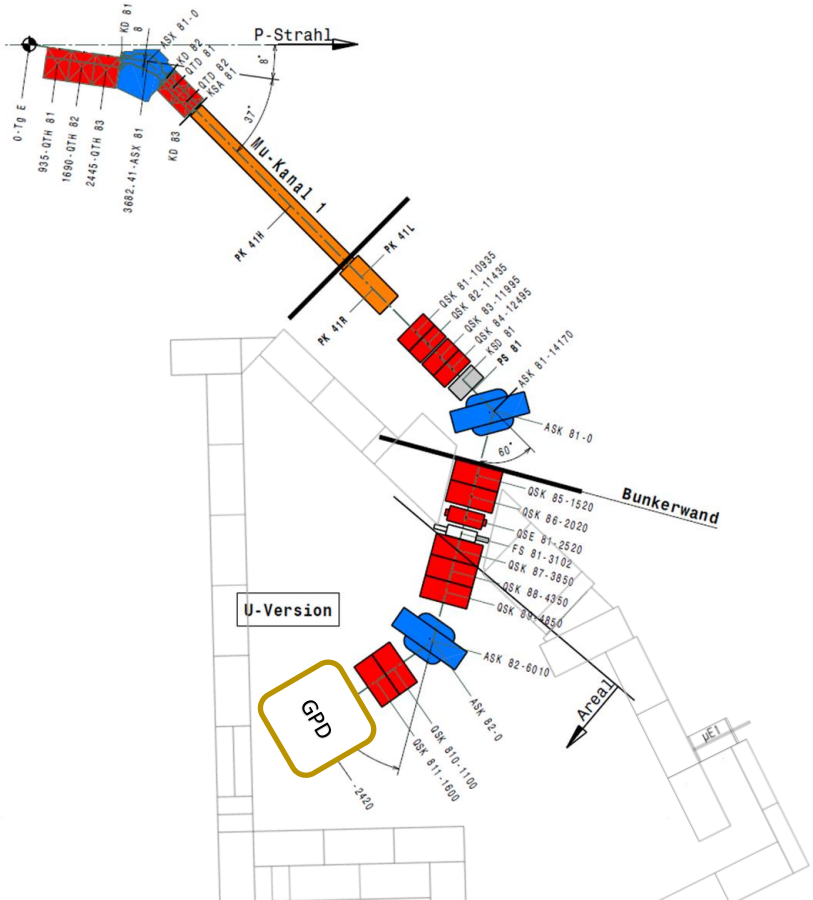
Current status of μE1

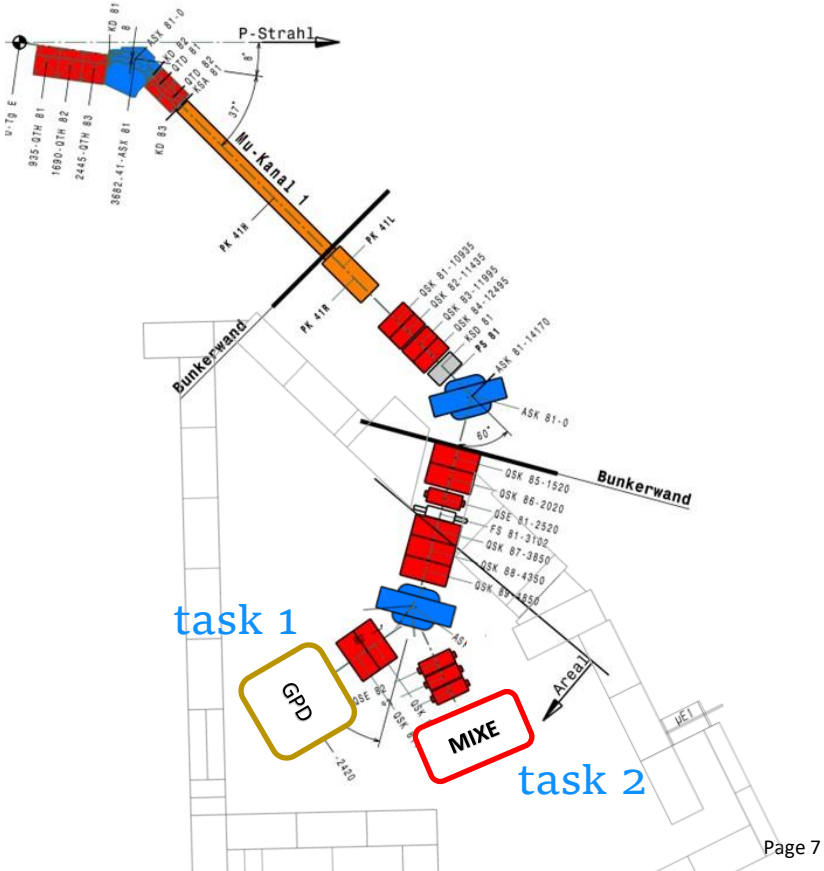


- Long Decay channel:
  - wider momentum range
    ~ 125 MeV/c
  - Higher flux
    > 10^7 μ-/s
- Extraction part:
  - 2 bending magnets and 13 quadrupoles
  - Allow for optimizing for good beam properties

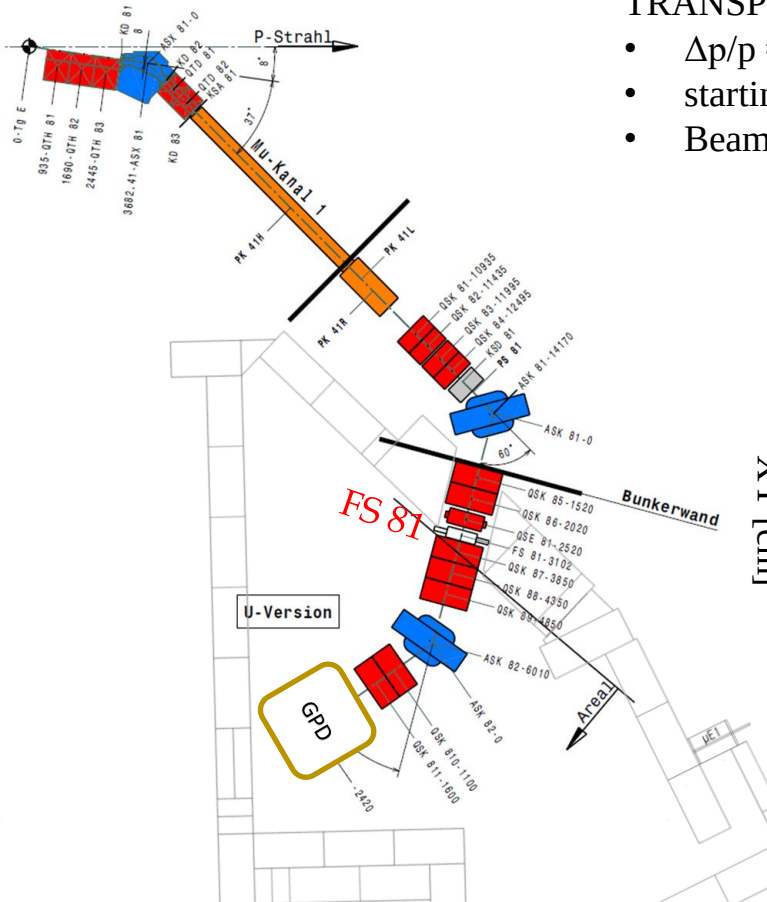
- GPD (General Purpose Decay Channel Instrument),
  - Enough space for a new bunch
  - limited impact on the old application

Current status of µE1



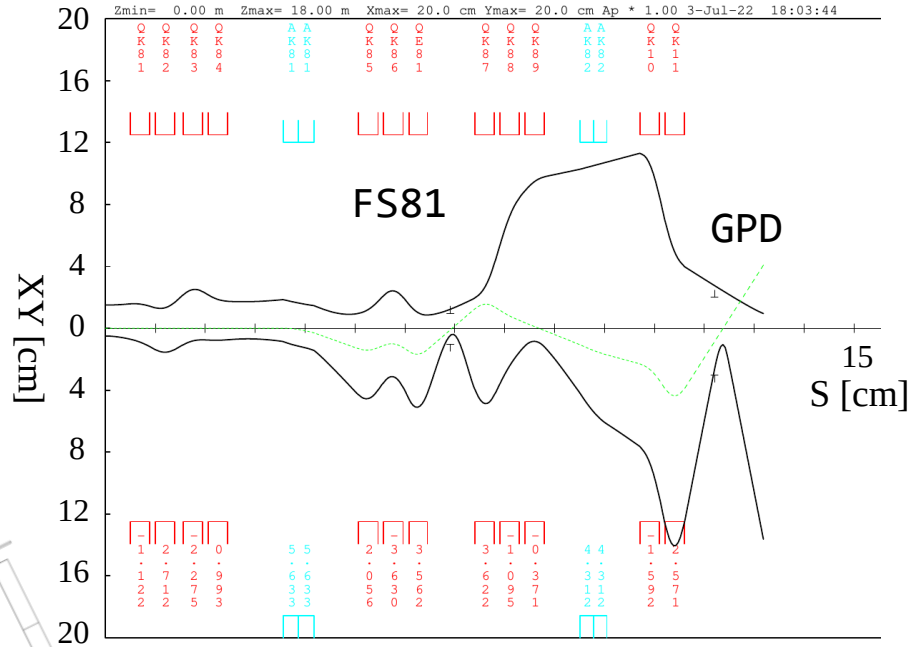


Current status of μE1



TRANSPORT calculation of beam envelope for GPD setting :

- Δp/p = 3%, 1st order calculation
- starting from the extraction of decay channel
- Beam Properties at slit FS81 and GPD: beam size/ achromatic



The parameters of elements in the simulation

TRANSPORT

TURTLE

the envelope of beam

the multi-particle transmission.

To check the parameters of magnets in the input file:

Measurement

Calculation

} The same current setting

The parameters of elements in the simulation

TRANSPORT

TURTLE

→

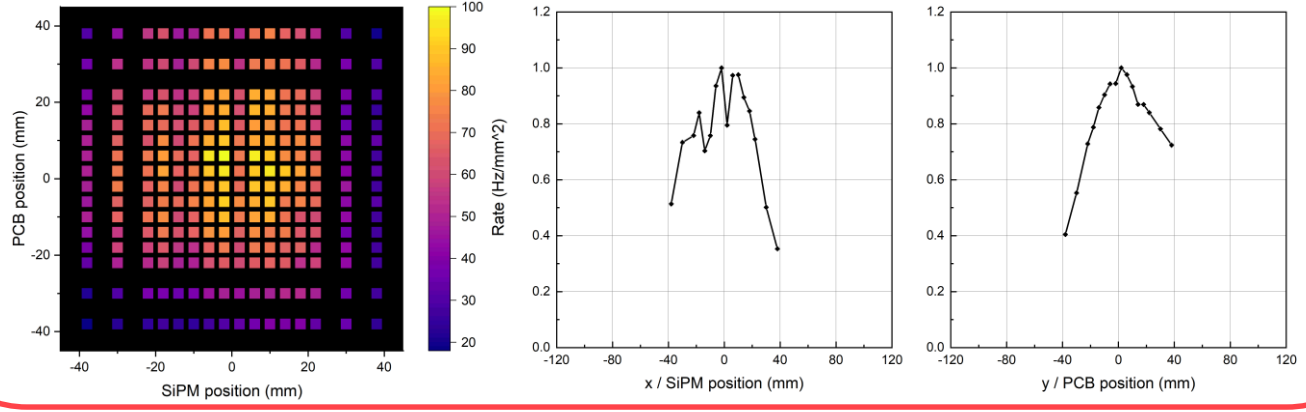
the envelope of beam

the multi-particle transmission.

To check the parameters of magnets in the input file:

Measurement

- **muon beam spot** and **horizontal and vertical distributions** at 50 MeV/c at sample position of μE1 beamline;
- December 2021, by ***Lars Gerchow*** & ***Sayani Biswas***



The parameters of elements in the simulation

TRANSPORT

TURTLE

→ **the envelope of beam**

the multi-particle transmission.

To check the parameters of magnets in the input file:

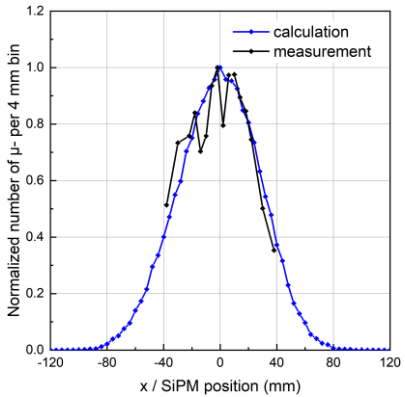
Measurement

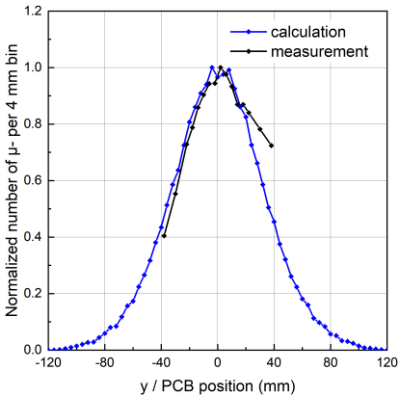
Calculation

} The same current setting → successful alignment and calibration of elements

- the fringe field of quadrupoles
- the pole face rotations of bending magnets

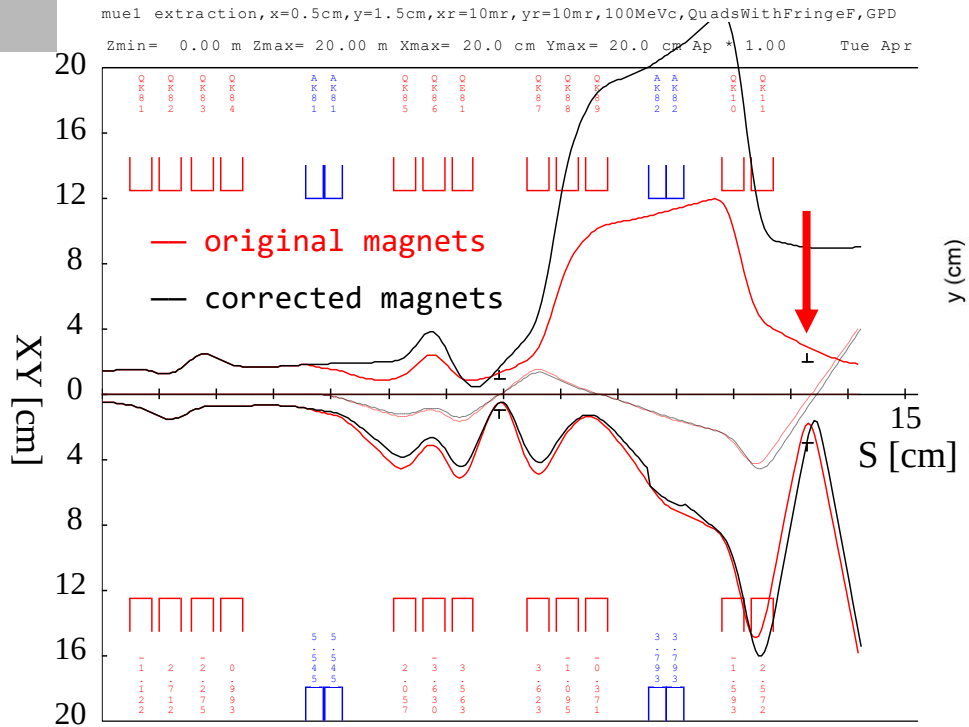
	mean x (mm)	mean y (mm)	std_x (mm)	std_y (mm)
SiPM	-1.56	6.12	32.1	35.8
TURTLE	-0.09	0.23	29.5	31.7

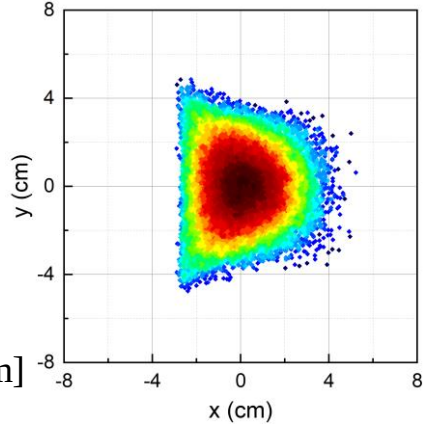




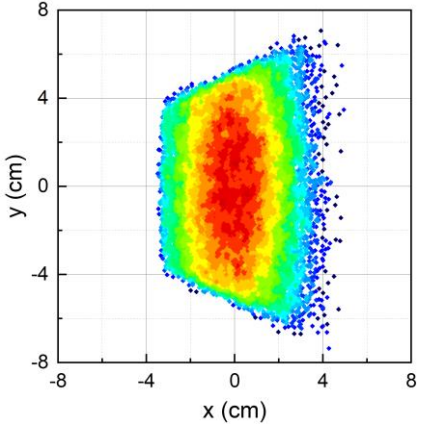
The parameters of elements in the simulation

A comparison of beam envelops and beam spots with different definitions of magnets for the GPD setting





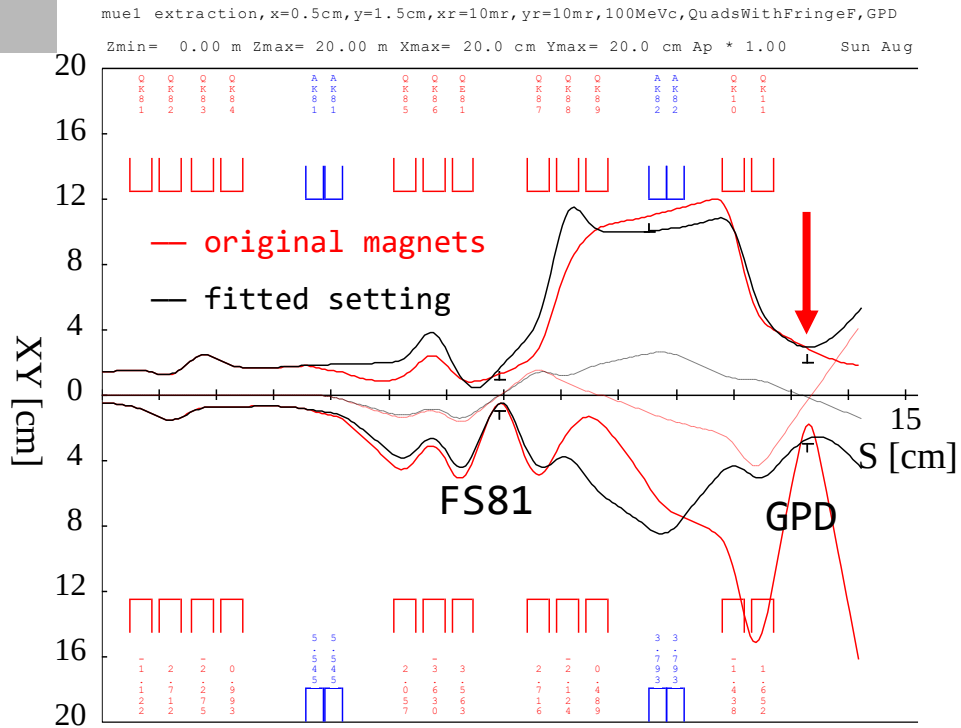
Original magnets,
2nd order calculation,
Δp/p=3%

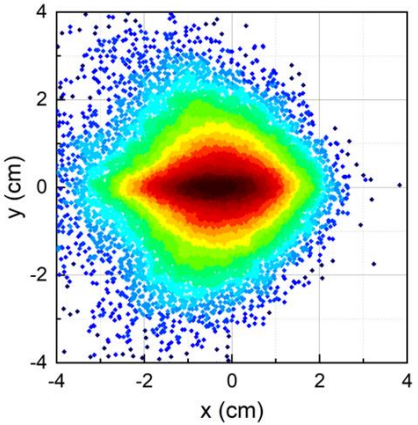


Corrected magnets,
2nd order calculation,
Δp/p=3%

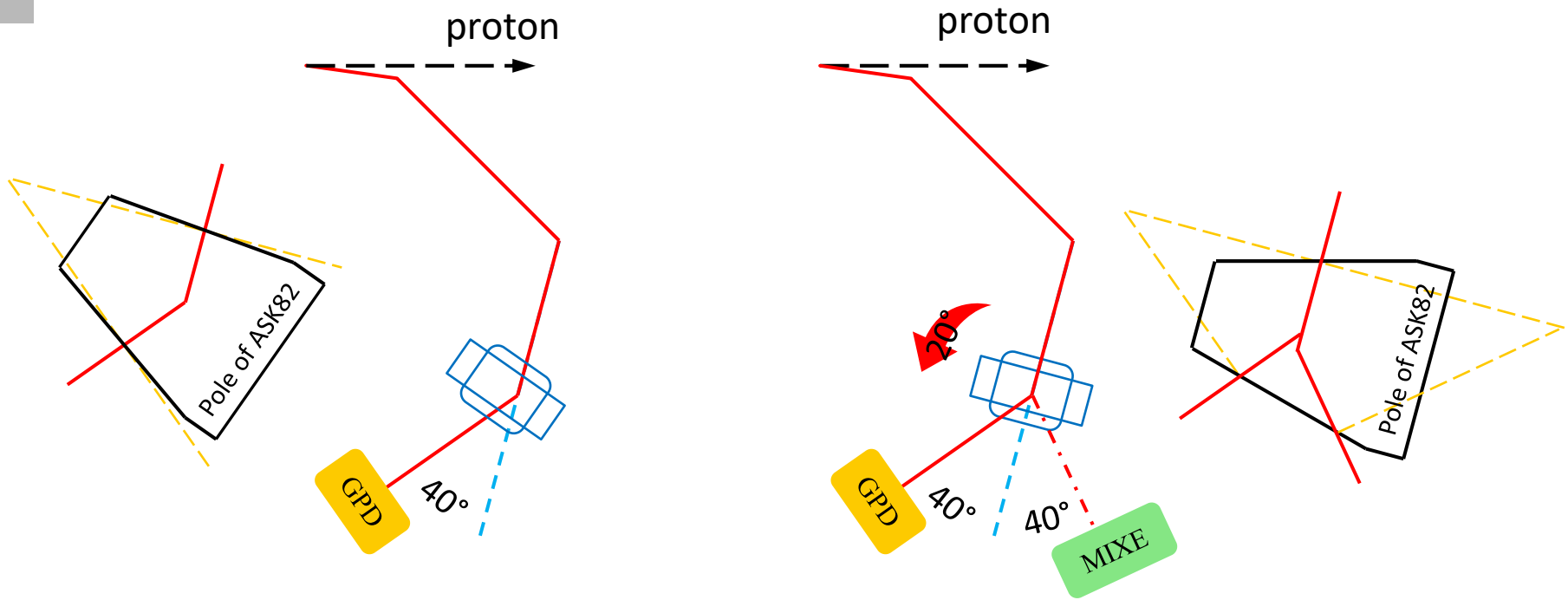
The parameters of elements in the simulation

The fitted TRANSPORT beam optics and TURTLE simulation for the GPD (2nd order calculation, Δp/p=3%)



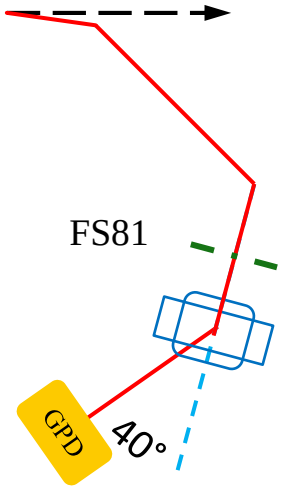


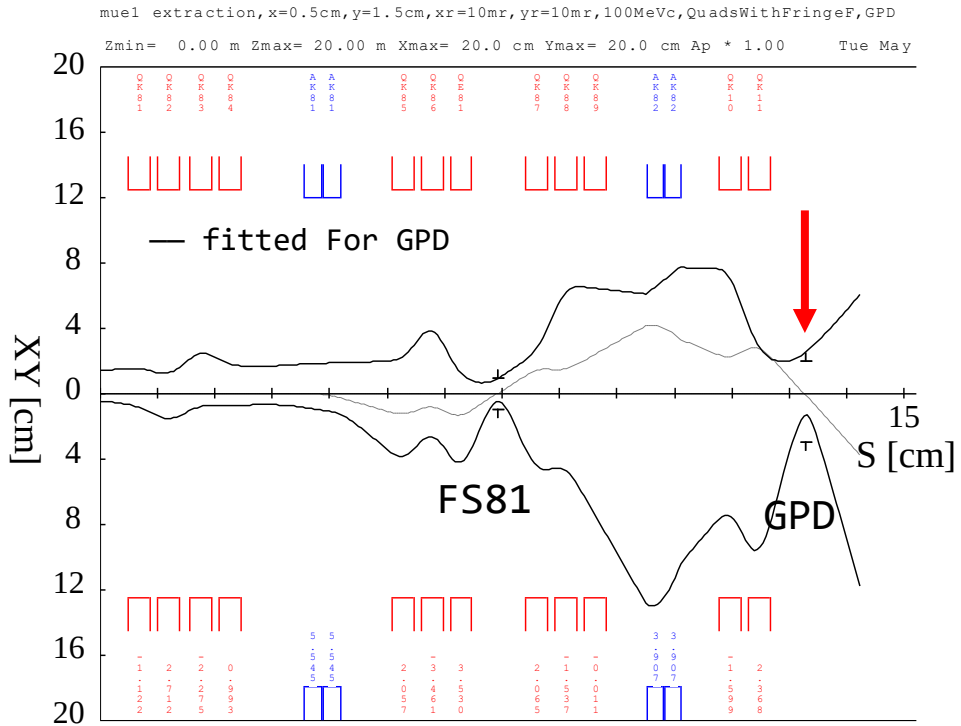
Beam envelope calculation of μE1 with new layout

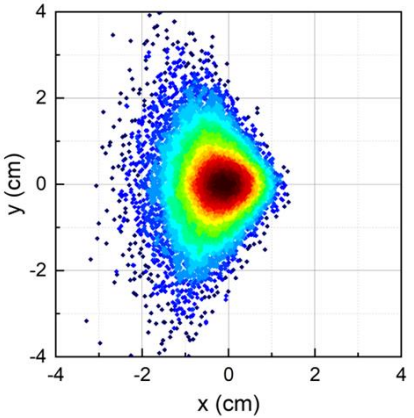


Beam envelope calculation of μE1 with new layout

The fitted TRANSPORT beam optics and TURTLE simulation for the original GPD side with a rotated bending magnet
(2^{nd} order calculation, $\Delta p/p=3\%$)

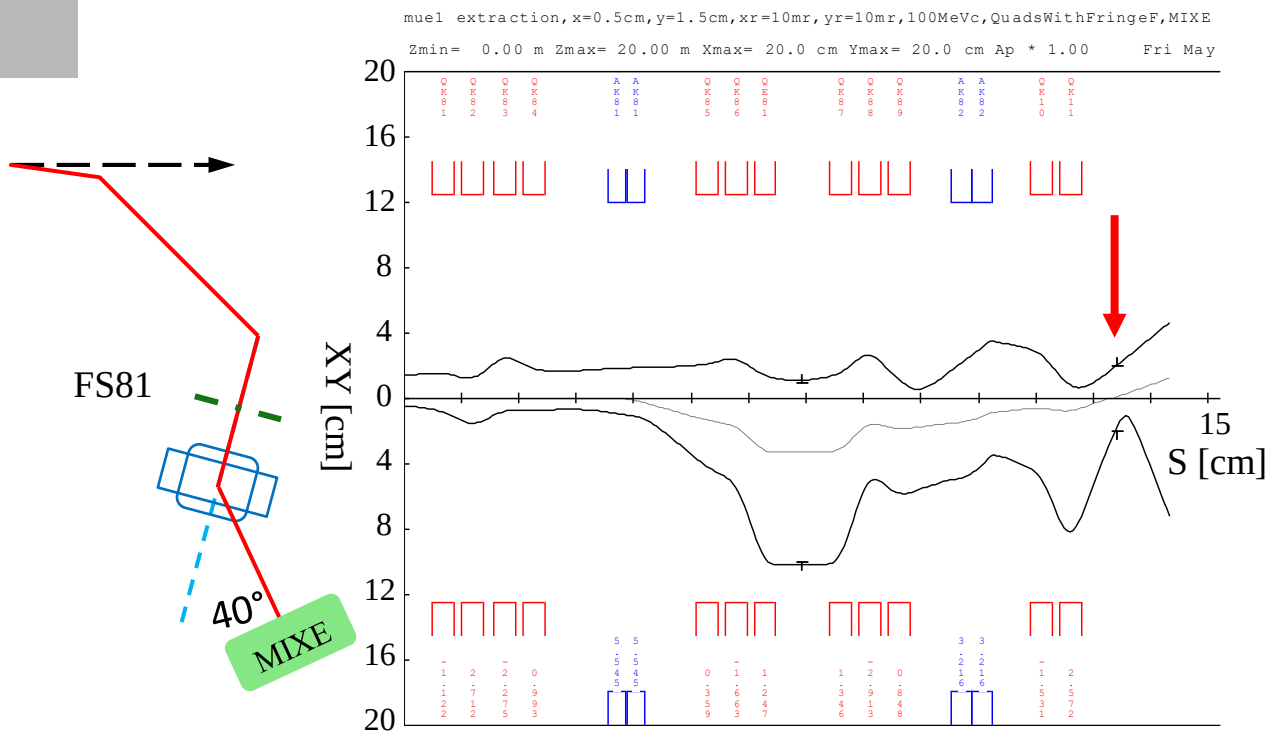






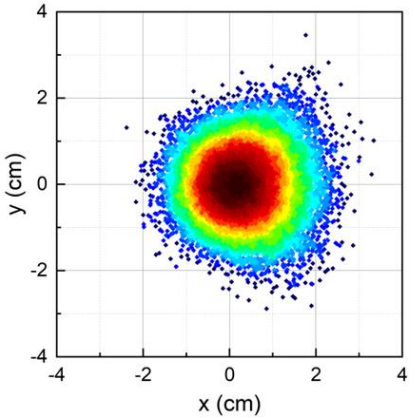
Beam envelope calculation of μE1 with new layout

For MIXE (rotated ASK82): Calculations of beam envelopes, 2nd order calculation, Δp/p=3%



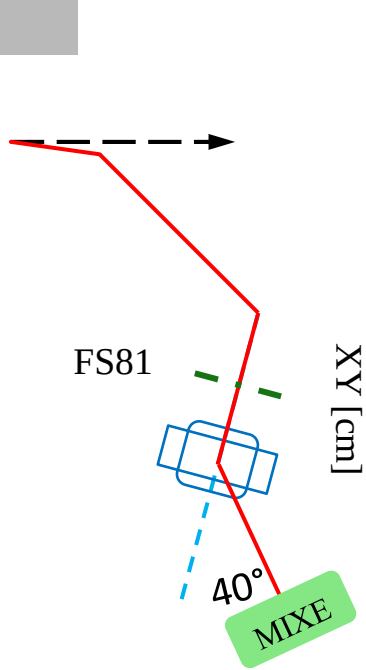
total opening of slit ~25 cm

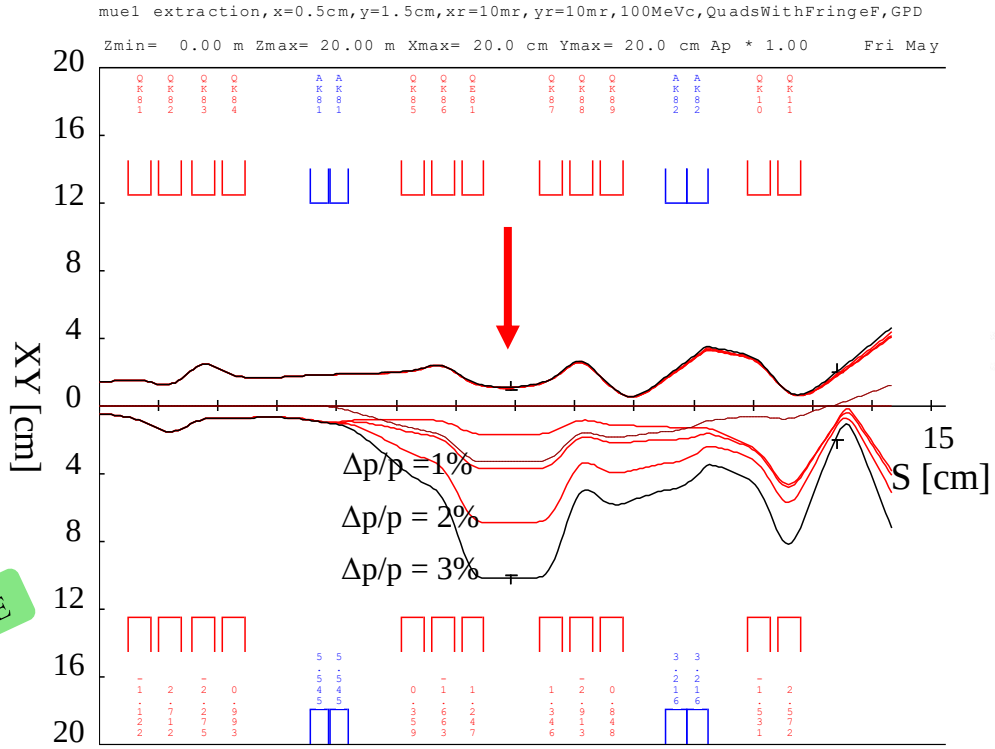
big momentum dispersion ~4 cm

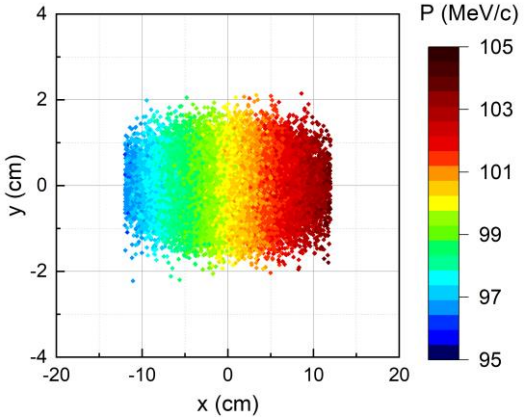


Beam envelope calculation of μE1 with new layout

For MIXE (rotated ASK82): Calculations of beam envelopes, 2nd order calculation, Δp/p=0、1、2、3%

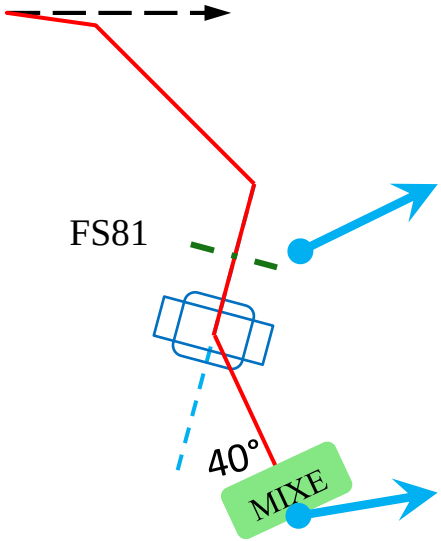




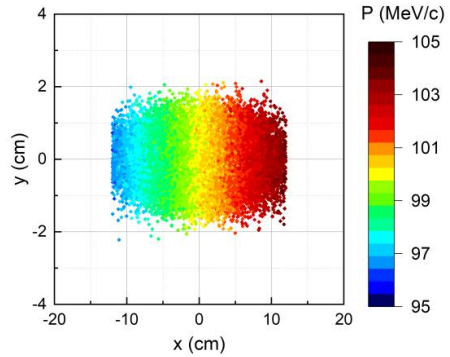


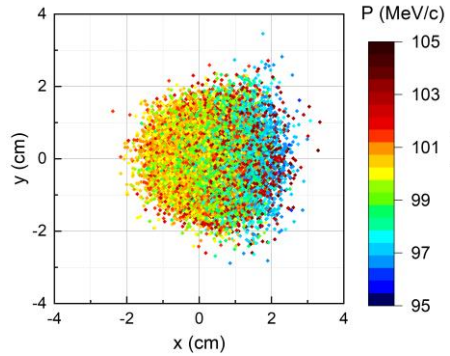
Beam envelope calculation of μE1 with new layout

For MIXE (rotated ASK82): Calculations of beam distribution on slit and end separately, 2nd order calculation

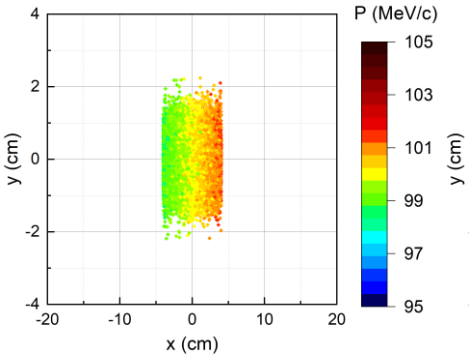


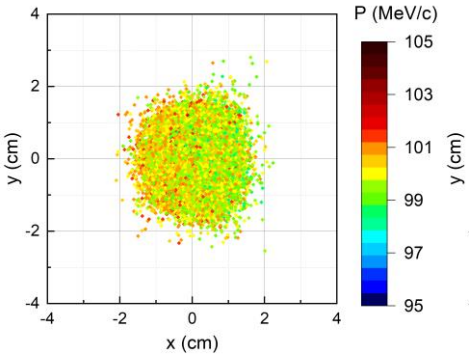
Half opening of slit Δx=12 cm



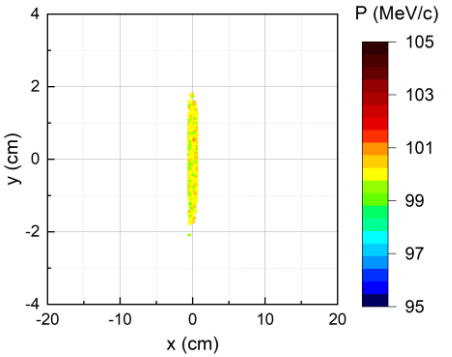


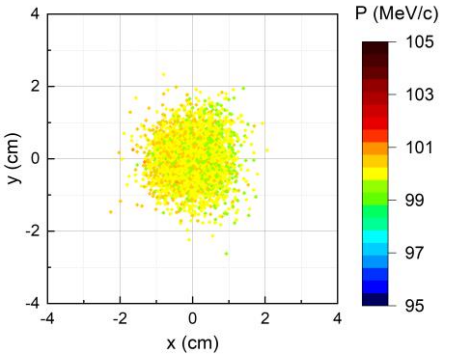
Half opening of slit Δx=4 cm





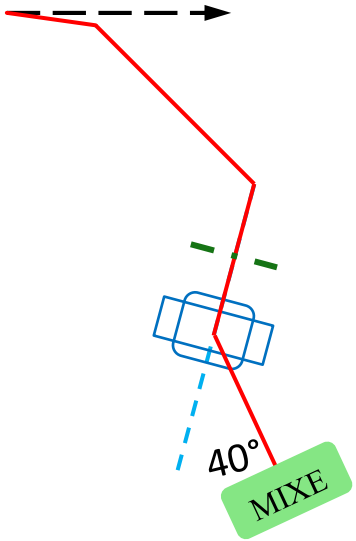
Half opening of slit Δx=0.5 cm

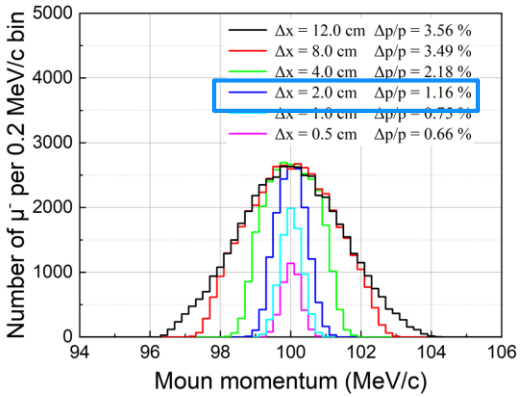


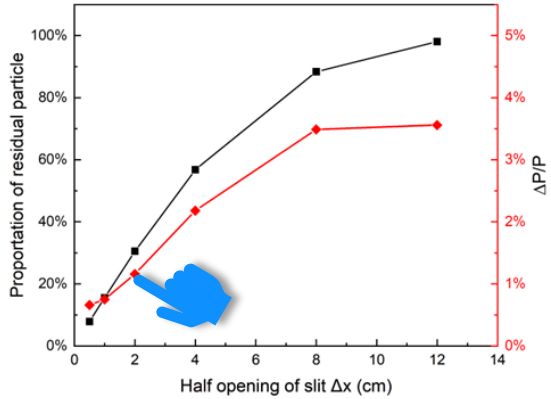


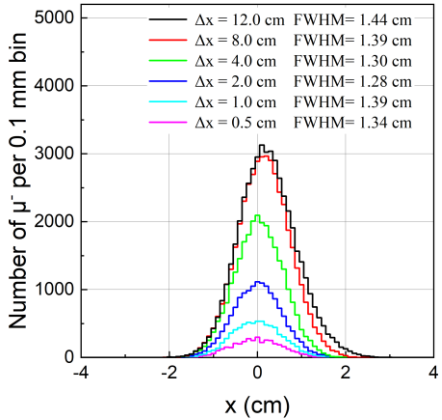
Beam envelope calculation of μE1 with new layout

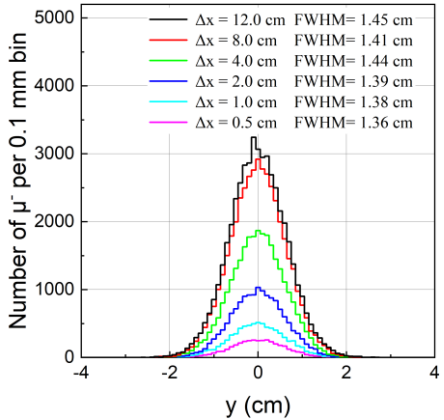
For MIXE (rotated ASK82): Δx - half jaw opening dp/p – momentum distribution at sample area (FWHM)





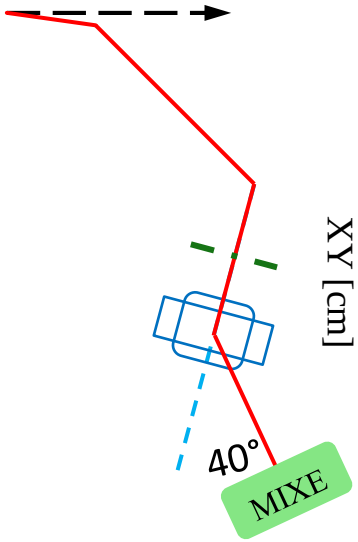


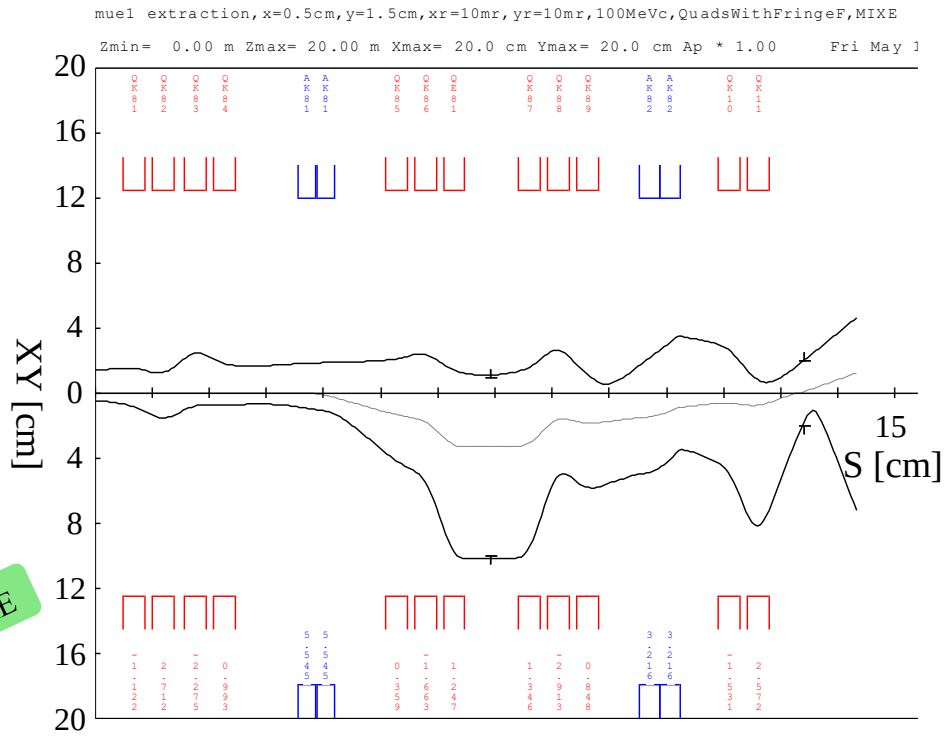




Beam envelope calculation of μE1 with new layout

For MIXE (rotated ASK82): the new branch of μE1 as a promising route for meeting the requirements of MIXE, which sets the stage for a significant expansion of muon applications at PSI





Main characteristics of MIXE settings according to calculation:

- Additional 2 quadrupoles are needed
- QSK87/88/89 are almost operated symmetrically to QSK85/86/QSE81
- On FS81, the momentum dispersion can be maximized
- for MIXE operation, the dp/p reaches lower than 1% if slits have the half opening of smaller than 20 mm
- Beam spot ~ 1.5 cm × 1.5 cm (FWHM)
- Scaling the magnetic system to the desired momenta → 3D bulk elemental analysis

Muon beam line simulation for negative muons

Thanks For Listening

Reference

[1] L. Gerchow et al., “GermanIum array for non-destructive testing (GIANT) setup for muon-induced x-ray emission (MIXE) at the Paul Scherrer Institute,” Review of Scientific Instruments, vol. 94, no. 4, p. 045106, Apr. 2023, doi: 10.1063/5.0136178.

[2] S. Biswas et al., “The non-destructive investigation of a late antique knob bow fibula (Bügelknopffibel) from Kaiseraugst/CH using Muon Induced X-ray Emission (MIXE),” Herit Sci, vol. 11, no. 1, p. 43, Mar. 2023, doi: 10.1186/s40494-023-00880-0.

[3] S. Biswas et al., “Characterization of a Continuous Muon Source for the Non-Destructive and Depth-Selective Elemental Composition Analysis by Muon Induced X- and Gamma-rays,” Applied Sciences, vol. 12, no. 5, p. 2541, Feb. 2022, doi: 10.3390/app12052541.

[4] K. Shimomura et al., “Present status of J-PARC MUSE,” J. Phys.: Conf. Ser., vol. 2462, no. 1, p. 012033, Mar. 2023, doi: 10.1088/1742-6596/2462/1/012033.

[5] A. D. Hillier, D. McK. Paul, and K. Ishida, “Probing beneath the surface without a scratch — Bulk non-destructive elemental analysis using negative muons,” Microchemical Journal, vol. 125, pp. 203–207, Mar. 2016, doi: 10.1016/j.microc.2015.11.031.

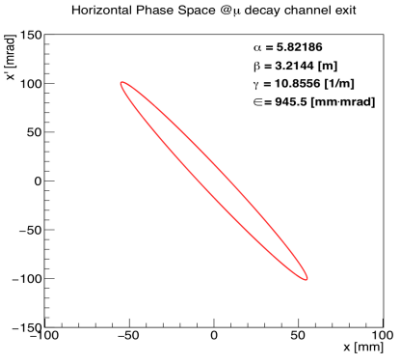
[6] T. Nakano et al., “The Research Center for Nuclear Physics at Osaka University,” Nuclear Physics News, vol. 29, no. 4, pp. 4–9, Oct. 2019, doi: 10.1080/10619127.2019.1676109.

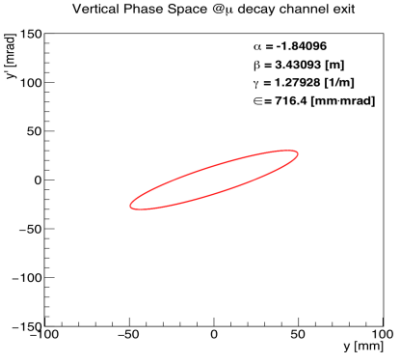
[7] F. Foroughi, “μE1 secondary beam line,” Oct. 1997.

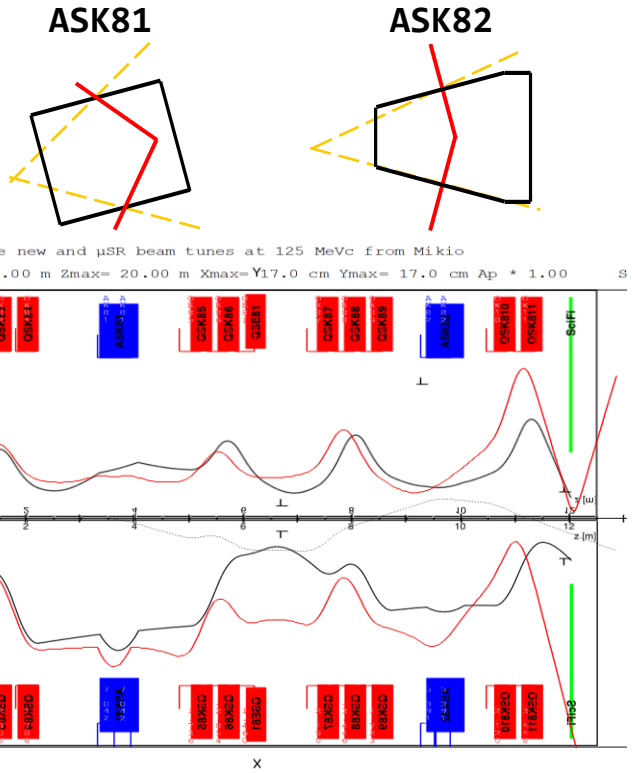
[8] https://www.psi.ch/en/smus/beamlines

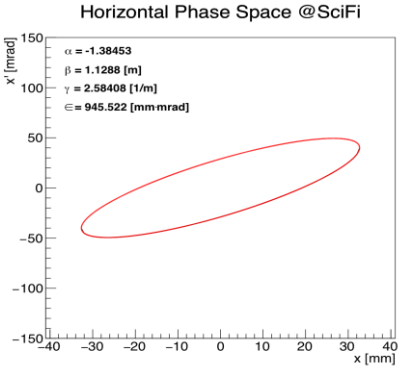
[9] https://mlfinfo.jp/en/aboutmlf/muon.html

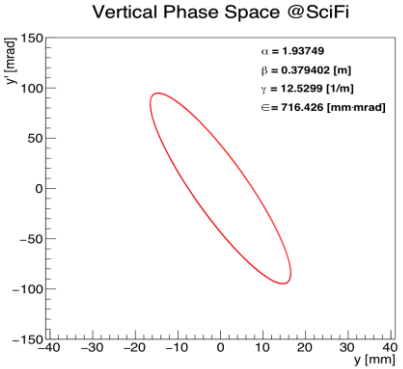
Backup









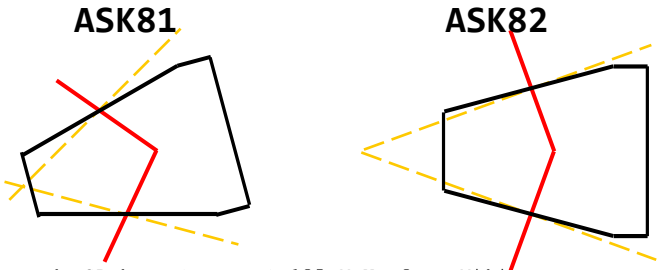


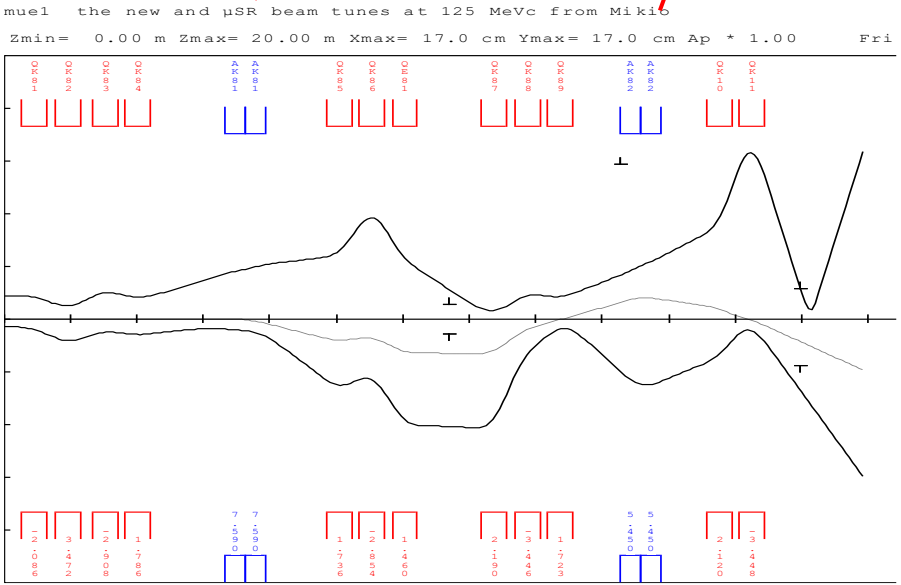
Horizontal and vertical 1σ phase space ellipses at the exit of the muon decay channel of the μE1 beamline when using the new beam tune at 125 MeV/c

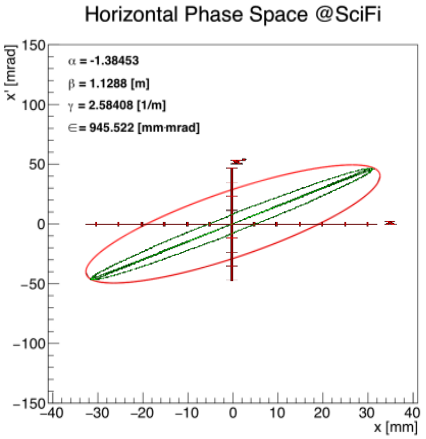
Measured horizontal and vertical phase space ellipses (1σ) at the SciFi detector position measured at the μE1 beamline

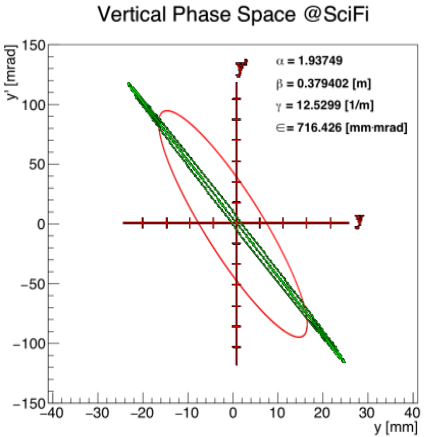
M. Sakurai et al, 2023.

Backup

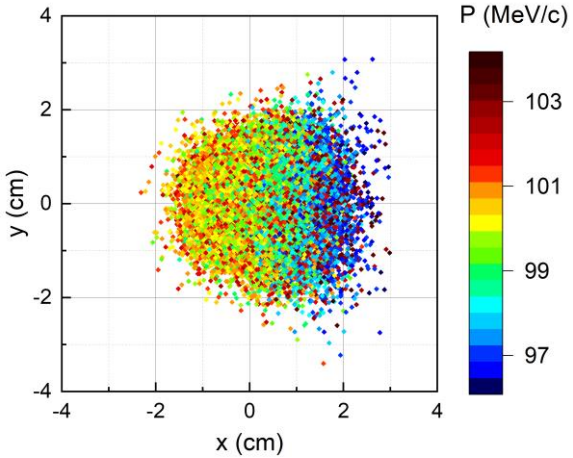

ASK81
ASK82

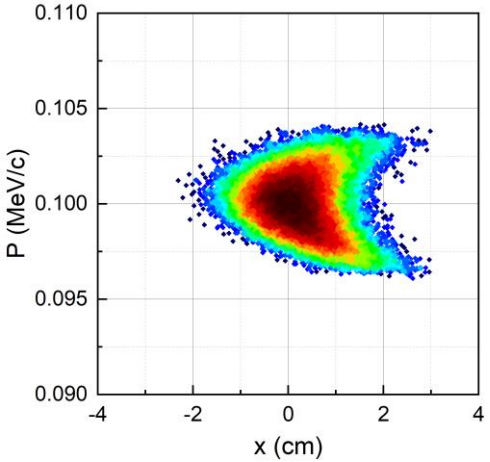

mue1 the new and μSR beam tunes at 125 MeVc from Mikie
Zmin= 0.00 m Zmax= 20.00 m Xmax= 17.0 cm Ymax= 17.0 cm Ap * 1.00
Fri


Horizontal Phase Space @SciFi
α = -1.38453
β = 1.1288 [m]
γ = 2.58408 [1/m]
∈ = 945.522 [mm·mrad]
x' [mrad]
x [mm]


Vertical Phase Space @SciFi
α = 1.93749
β = 0.379402 [m]
γ = 12.5299 [1/m]
∈ = 716.426 [mm·mrad]
y' [mrad]
y [mm]

Backup





Longitudinal phase space deformation

Cause by higher order effects

The parameters of elements in the simulation

- The fitted TRANSPORT beam optics and TURTLE simulation for the GPD (2nd order calculation, Δp/p=3%)
- Comparison of TRANSPORT and TURTLE of phase space ellipses at the sample position. (Δp/p=0%)