FFAG Applications for Muon Science

Akira Sato

Dept. of Physics, Osaka University

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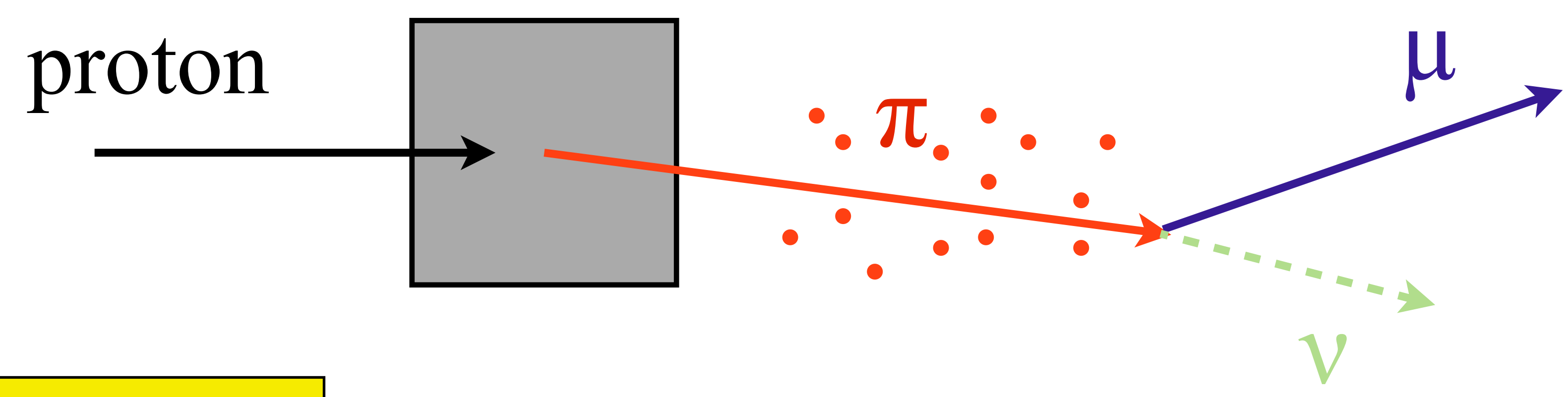
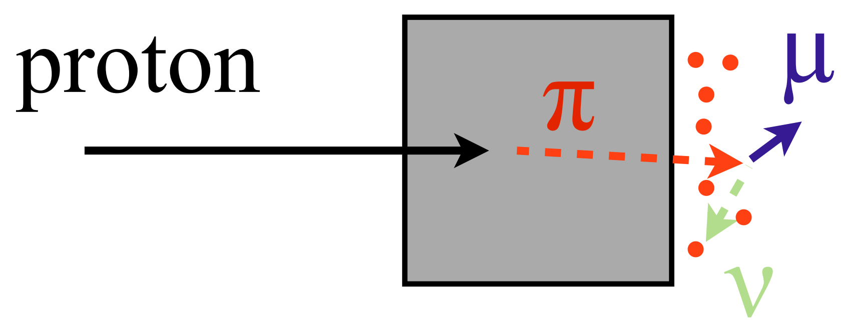
Three types of muon production

Decay muon



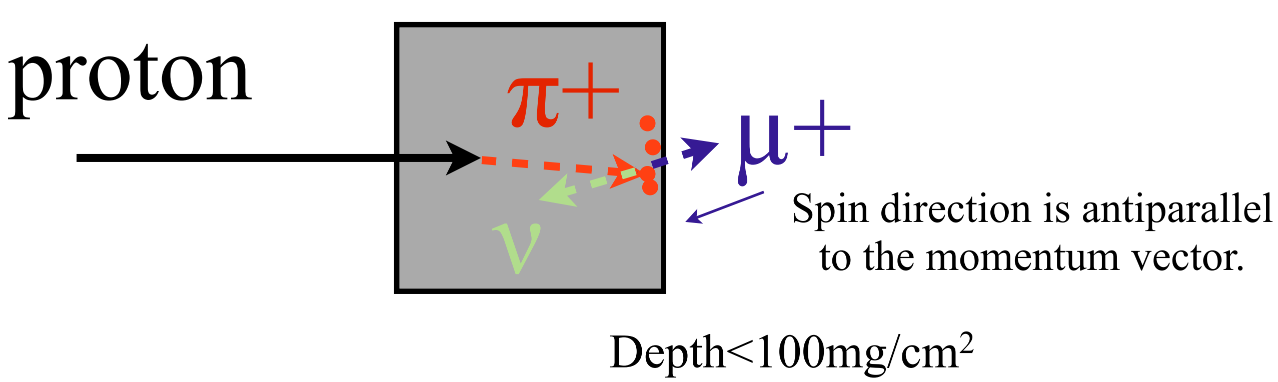
μ+ and μ-
Pol. > 80% (for ~70MeV/c)
p_{μ}>29.8MeV/c
Beam size large

Cloud muon



μ+ and μ-
Pol. = small
p_{μ}~40MeV/c
Beam size large

Surface muon



only μ+
Pol. = 100%
p_{μ}=29.8MeV/c
Beam size can be small

Users of the surface muon beam

- Material scientists (μSR users)
  - Muon spin precession in a material by its local magnetic field.
    - Pol.=100%, 29MeV/c, Small beam size, $10^{6\text{-}8}$μ+/s
- μ lepton flavor violation search with a DC beam
  - μ→eγ (MEG, MEG-II @ PSI)
    - 29MeV/c, Small beam size, 10^{8}μ+/s
  - μ→eee (mu3e @PSI)
    - 29MeV/c, Small beam size, **$10^{9\text{-}10}$μ+/s**
  - After the discovery of the μLFV signal, spin-dependent experiments are important to understand physics of the μLFV.
    - **Pol.=100%,** 29MeV/c, Small beam size, **$10^{10\text{-}11}$μ+/s**

A high intense surface μ study at PSI

PHYSICAL REVIEW ACCELERATORS AND BEAMS **19,** 024701 (2016)

Target studies for surface muon production

F. Berg,[1,2] L. Desorgher,[1,*] A. Fuchs,[1] W. Hajdas,[1] Z. Hodge,[1,2] P.-R. Kettle,[1,†] A. Knecht,[1,‡] R. Lüscher,[1] A. Papa,[1] G. Rutar,[1,2] and M. Wohlmuther[1]

[1]*Paul Scherrer Institute (PSI), CH5232 Villigen PSI, Switzerland*
[2]*Institute for Particle Physics, ETH Zurich, 8093 Zurich, Switzerland*

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Meson factories are powerful drivers of diverse physics programs. With beam powers already in the MW-regime attention has to be turned to target and beam line design to further significantly increase surface muon rates available for experiments. For this reason we have explored the possibility of using a neutron spallation target as a source of surface muons by performing detailed GEANT4 simulations with pion production cross sections based on a parametrization of existing data. While the spallation target outperforms standard targets in the backward direction by more than a factor 7 it is not more efficient than standard targets viewed under 90°. Not surprisingly, the geometry of the target plays a large role in the generation of surface muons. Through careful optimization, a gain in surface muon rate of between 30% and 60% over the standard "box-like" target used at the Paul Scherrer Institute could be achieved by employing a rotated slab target. An additional 10% gain could also be possible by utilizing novel target materials such as, e.g., boron carbide.

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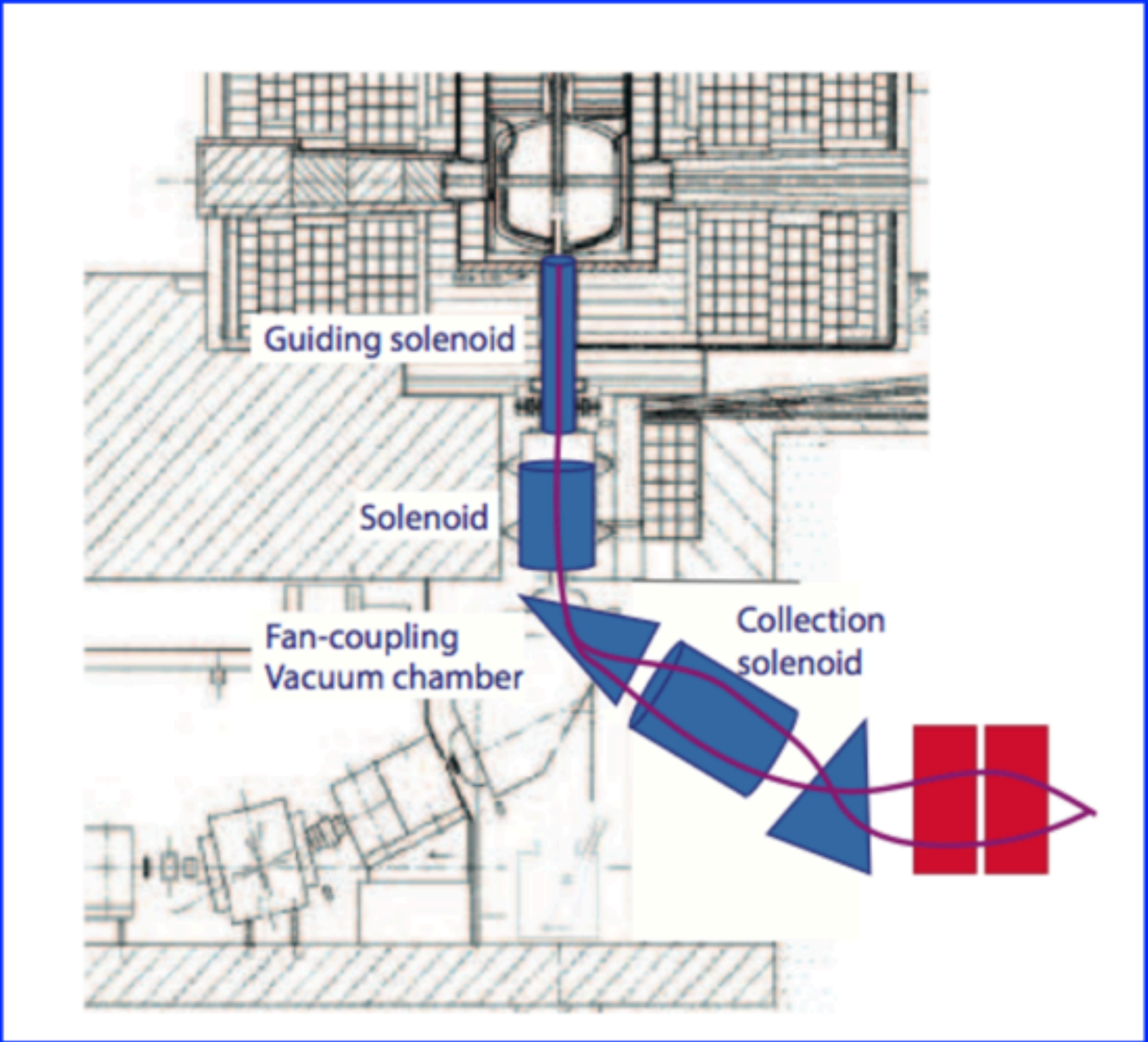
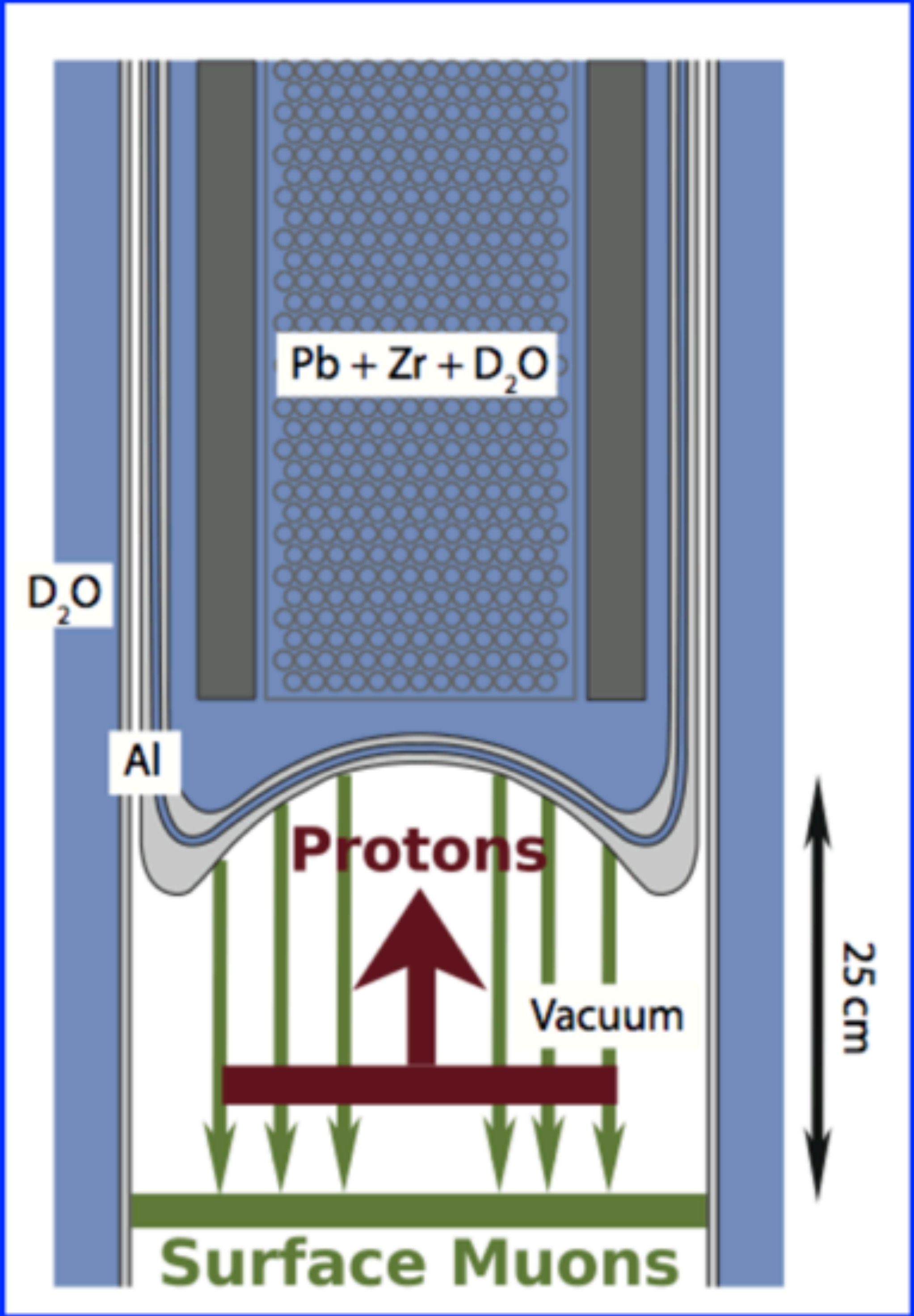
PHYSICAL REVIEW ACCELERATORS AND BEAMS 19, 024701 (2016)

A high intense surface μ study at PSI





Use the neutron spallation target as a surface muon target.

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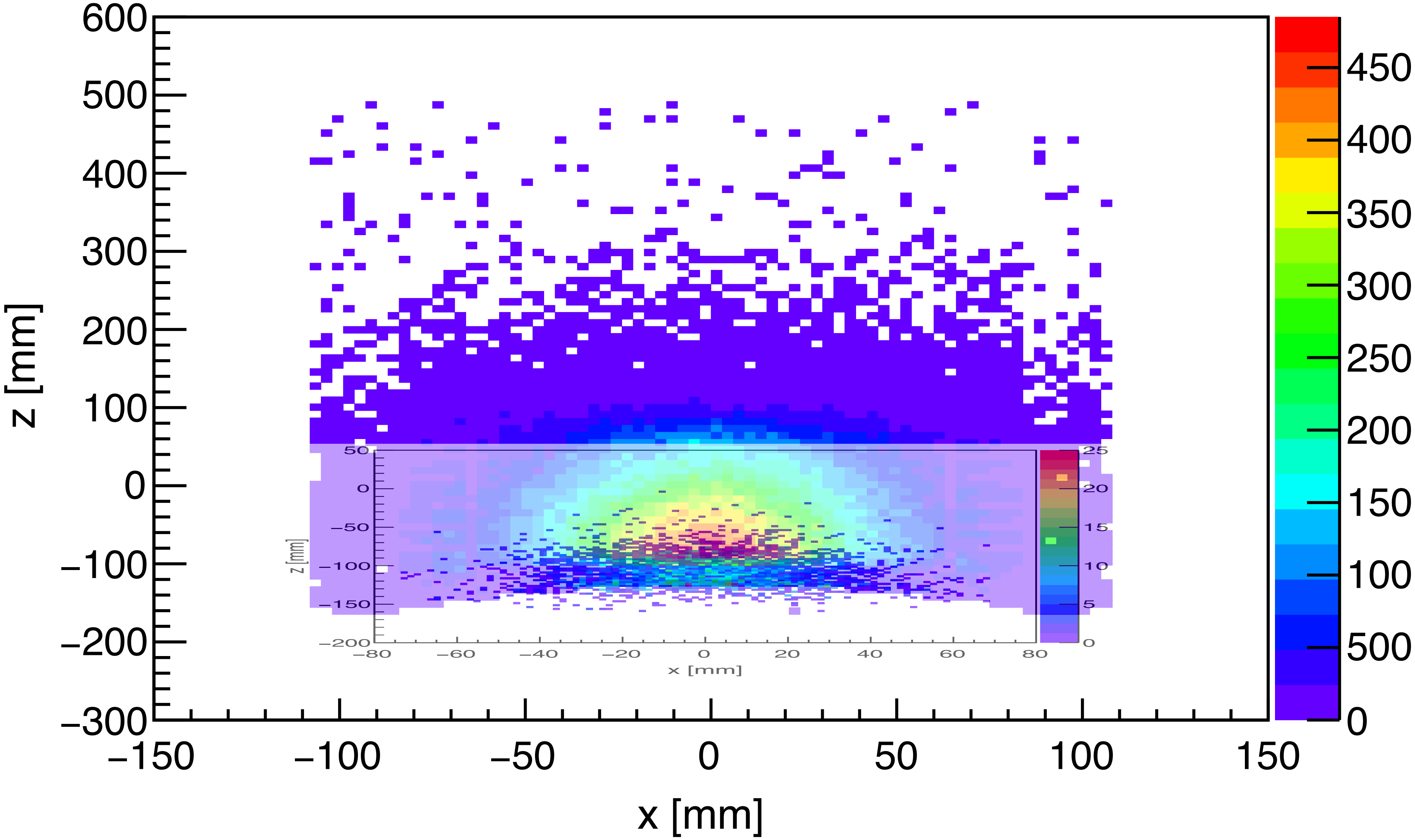
A high intense surface μ study at PSI

Use the neutron spallation target



Proton beam

$$\sigma_x = 21.4 \text{ mm}$$

$$\sigma_y = 29.6 \text{ mm}$$

$$I_p = 1.7 \text{ mA.}$$

Surface μ+ beam

$\mu^+/p = 8.8\text{x}10^{-6}$ (p_μ<29.8MeV/c)

$I\mu^+ = 9.4\text{x}10^{10} \mu^+/s$ (p_μ<29.8MeV/c)

$I\mu^+ = 4.3\text{x}10^{10} \mu^+/s$ (25.0<p_μ<29.8MeV/c)

A high intense surface μ study at PSI

Use a rotated slab target

Modeled as
L=40mm, W=6mm, H=40mm
in Geant4

Proton beam

$$\sigma_x = 0.75 \text{ mm}$$
$$\sigma_y = 1.25 \text{ mm}$$
$$I_p = 2.4 \text{ mA.}$$

Surface μ+ beam from the backward face

$\mu^+/p = 1.2\times10^{-6}$ (p_μ<29.8MeV/c)

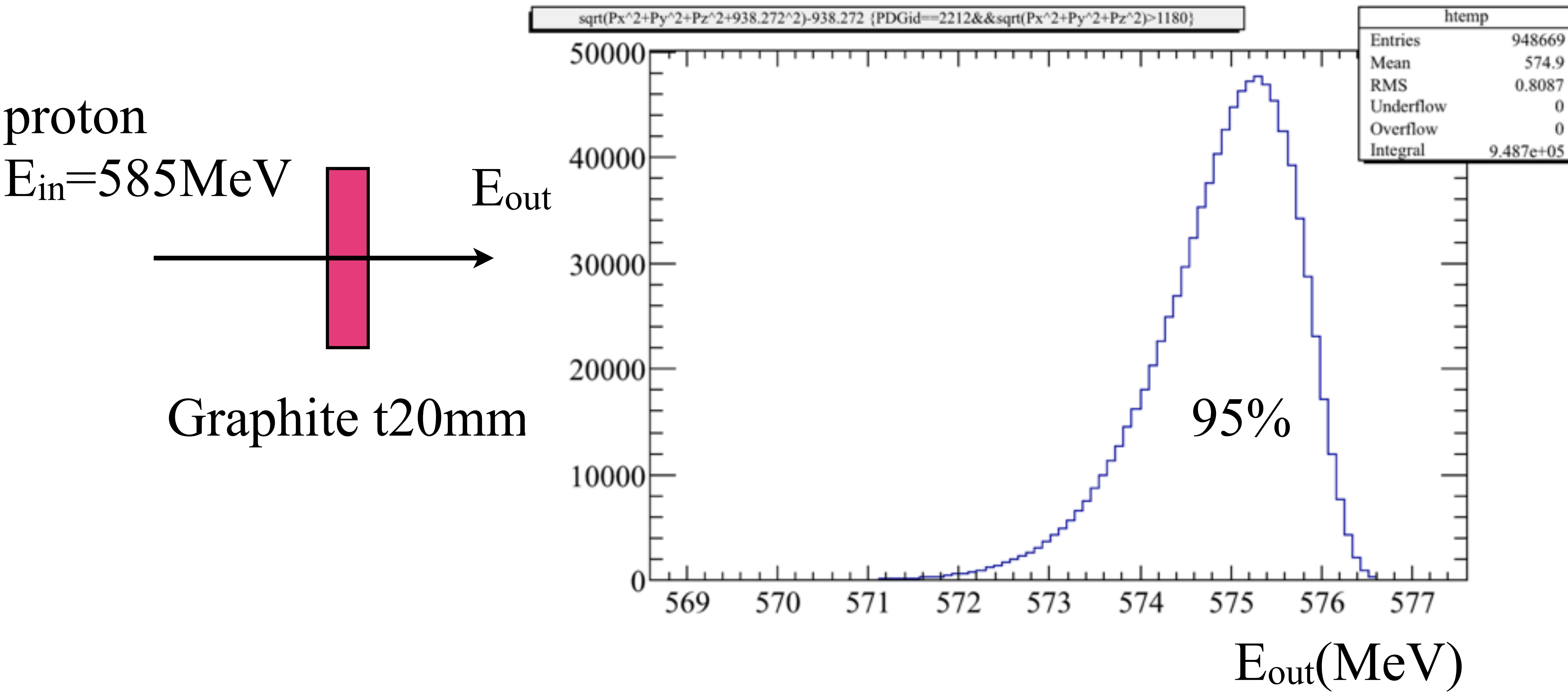
$I\mu^+ = 1.8\times10^{10} \mu^+/s$ (p_μ<29.8MeV/c)

TABLE I. Surface muon rates in μ^+/s for all muons with momenta below 29.8 MeV/c emitted from the various sides of target E for various lengths of the target in mm. The values for the side rates correspond to a single side only.

Length	Backward	Forward	Side
10	1.4×10^{10}	9.0×10^{9}	1.8×10^{10}
20	1.6×10^{10}	1.2×10^{10}	5.1×10^{10}
30	1.9×10^{10}	1.1×10^{10}	8.5×10^{10}
40	1.8×10^{10}	1.1×10^{10}	1.2×10^{11}
60	1.8×10^{10}	1.2×10^{10}	2.1×10^{11}

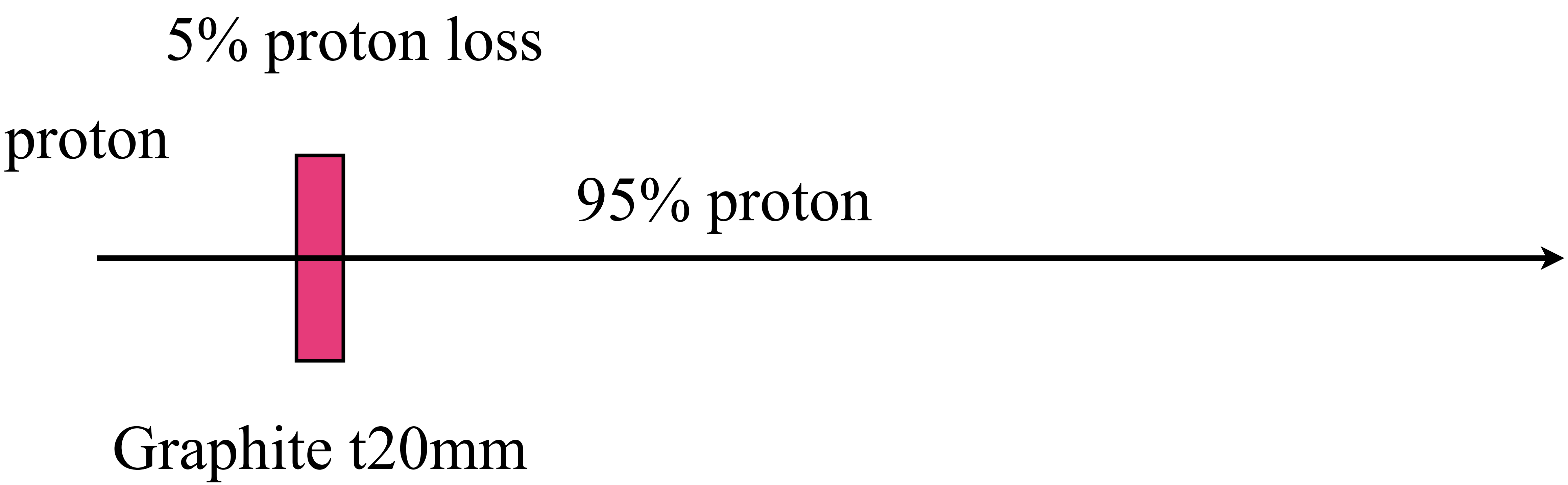
x 10 improvement is needed for the Pol. MEG/mu3e

Ratio of the used proton

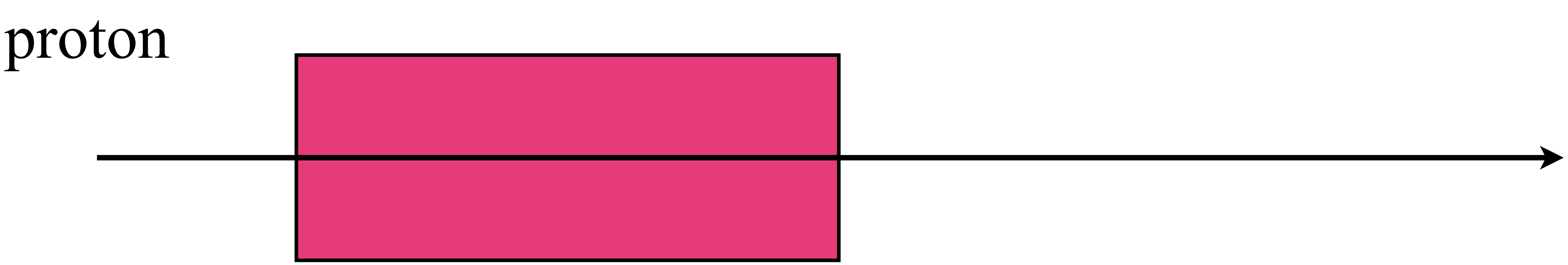


Recycle 95% protons to improve the surface muon yields. (x 20)

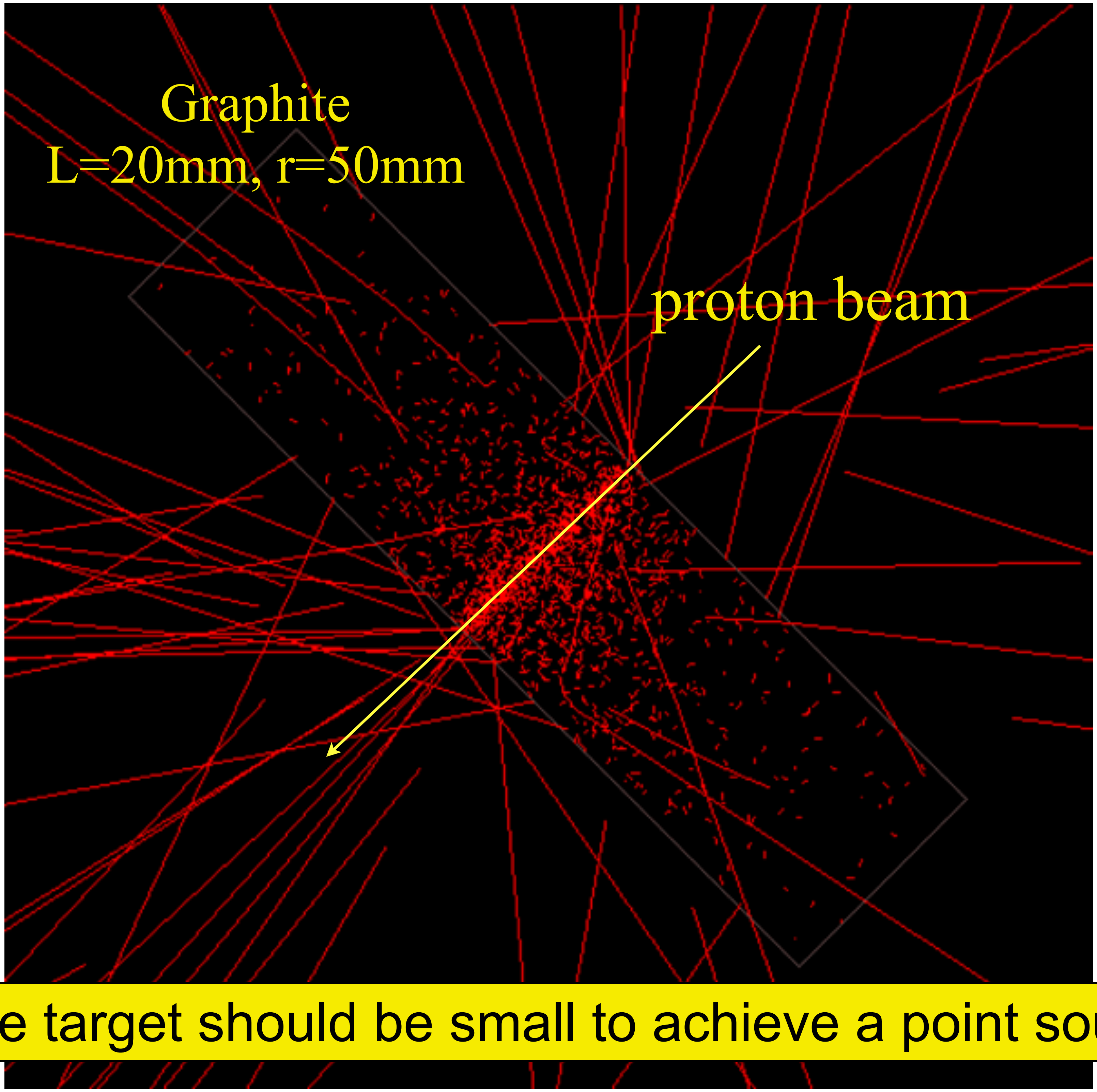
Solutions



Solutions

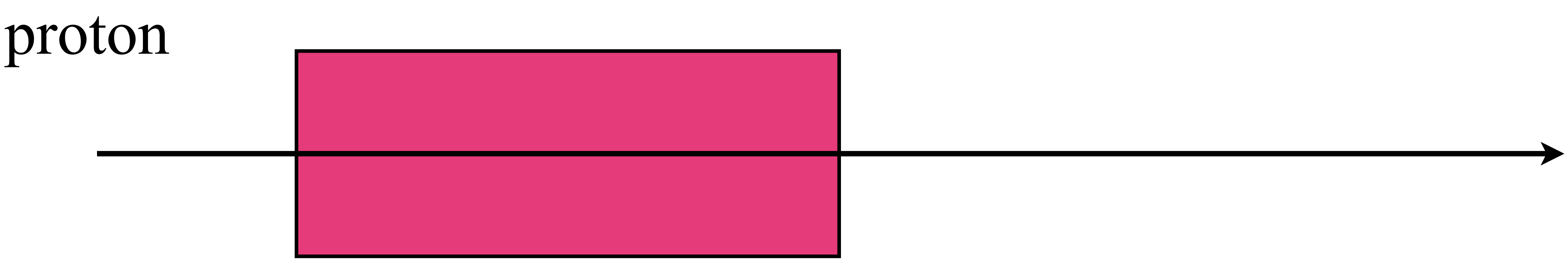


Muon from stopped pion



The target should be small to achieve a point source.

Solutions

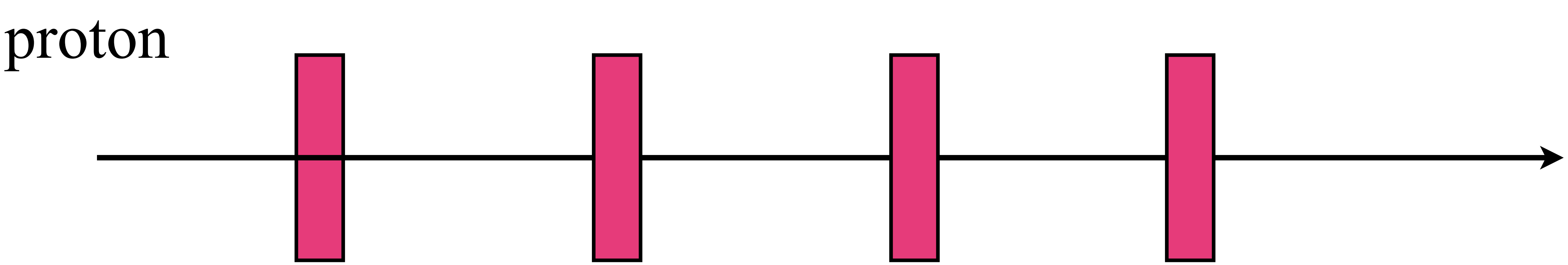


ΔE

Ep<E of pion production threshold cannot produce pions.

Not a point source

Solutions

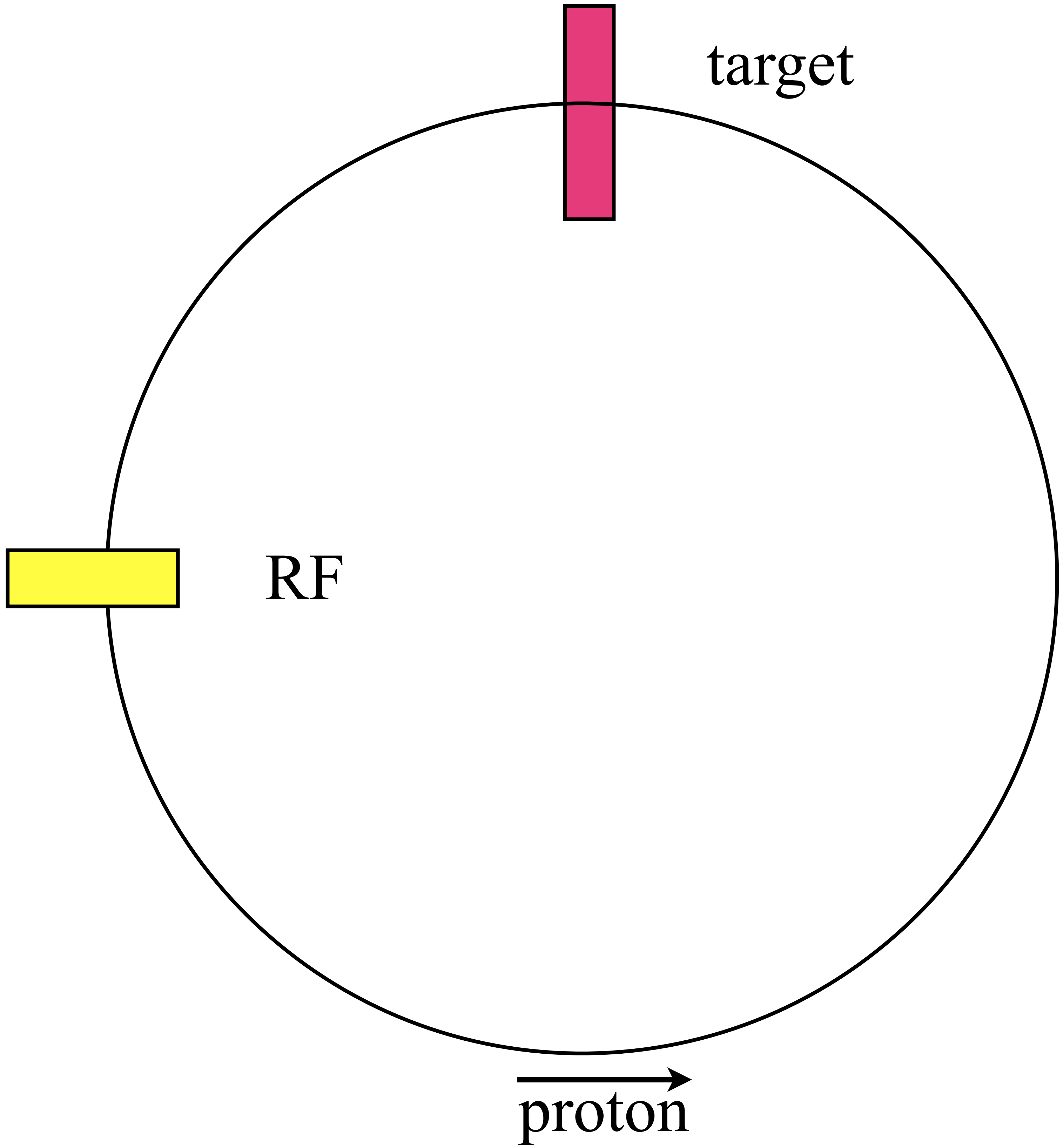


ΔE

Ep<E of pion production threshold cannot produce pions.

Many pi/mu capture systems

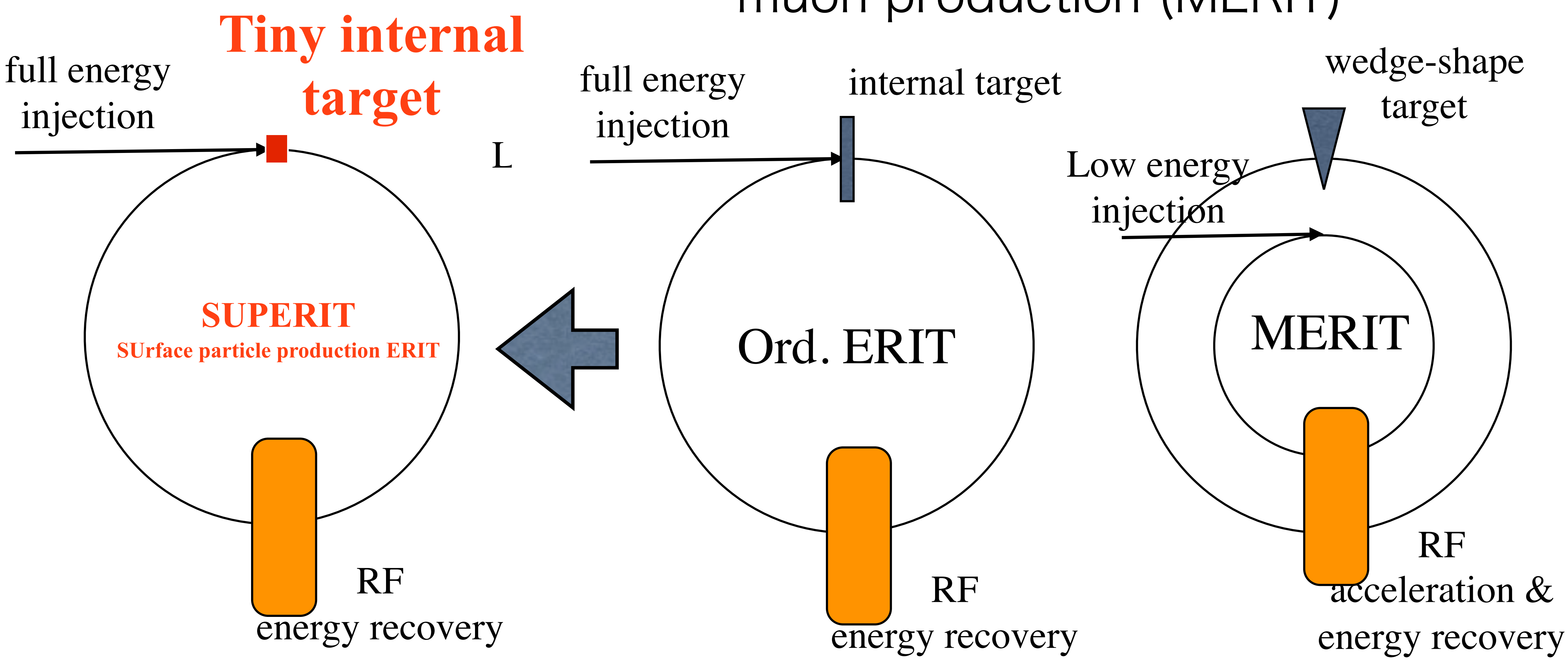
Solutions



ERIT for surface muon production

FFAG'17, Sept. 8-11,2017, Cornell Univ., Ithaca

Ord. ERIT vs. New ERIT for muon production (MERIT)

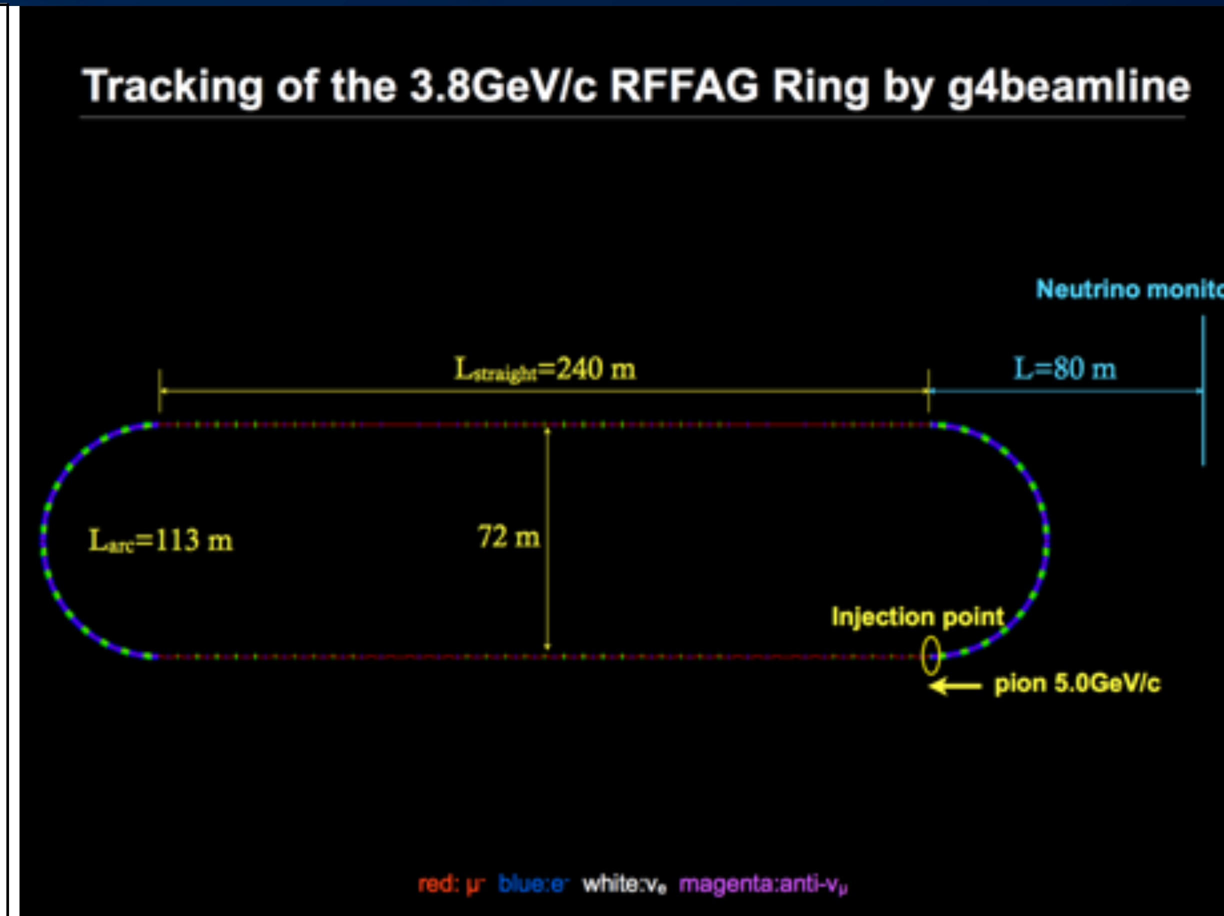


My last FFAG tracking study

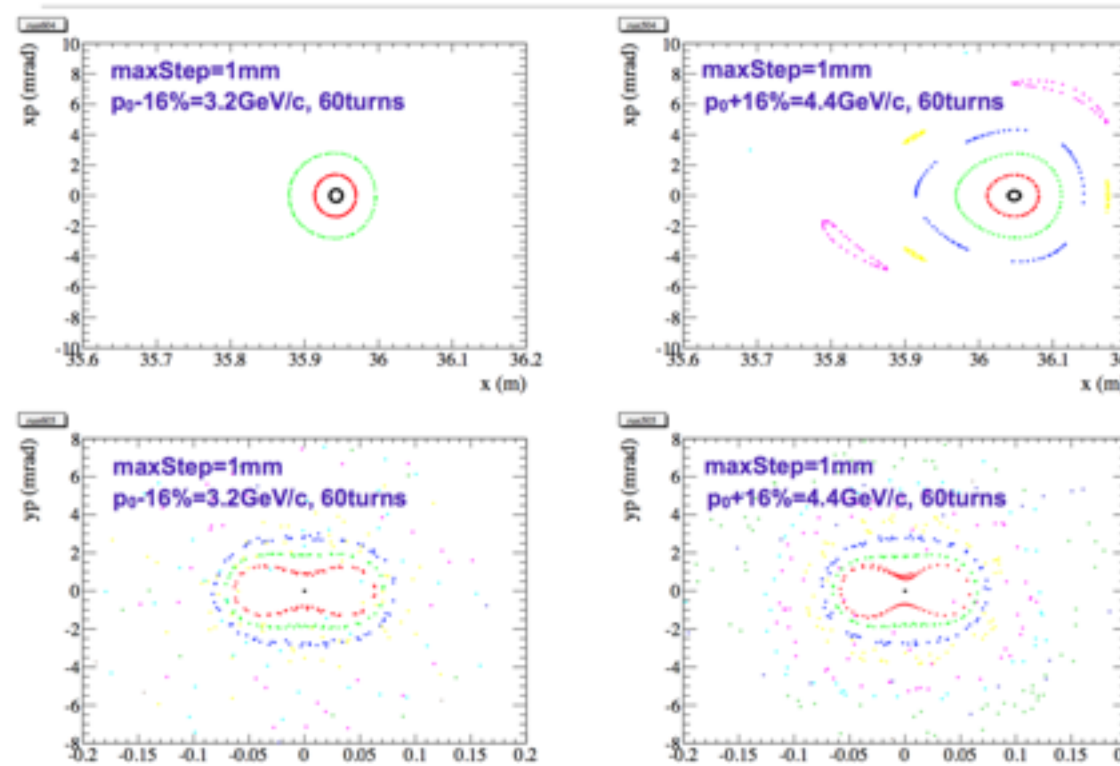
Simulation Study for RFFAG Decay Rings by g4beamline

Akira SATO
Department of Physics, Osaka University

FFAG12 workshop
2012/11/16, Osaka University
25+5 min



G4beamline results: p= p_0-16% and p_0+16%



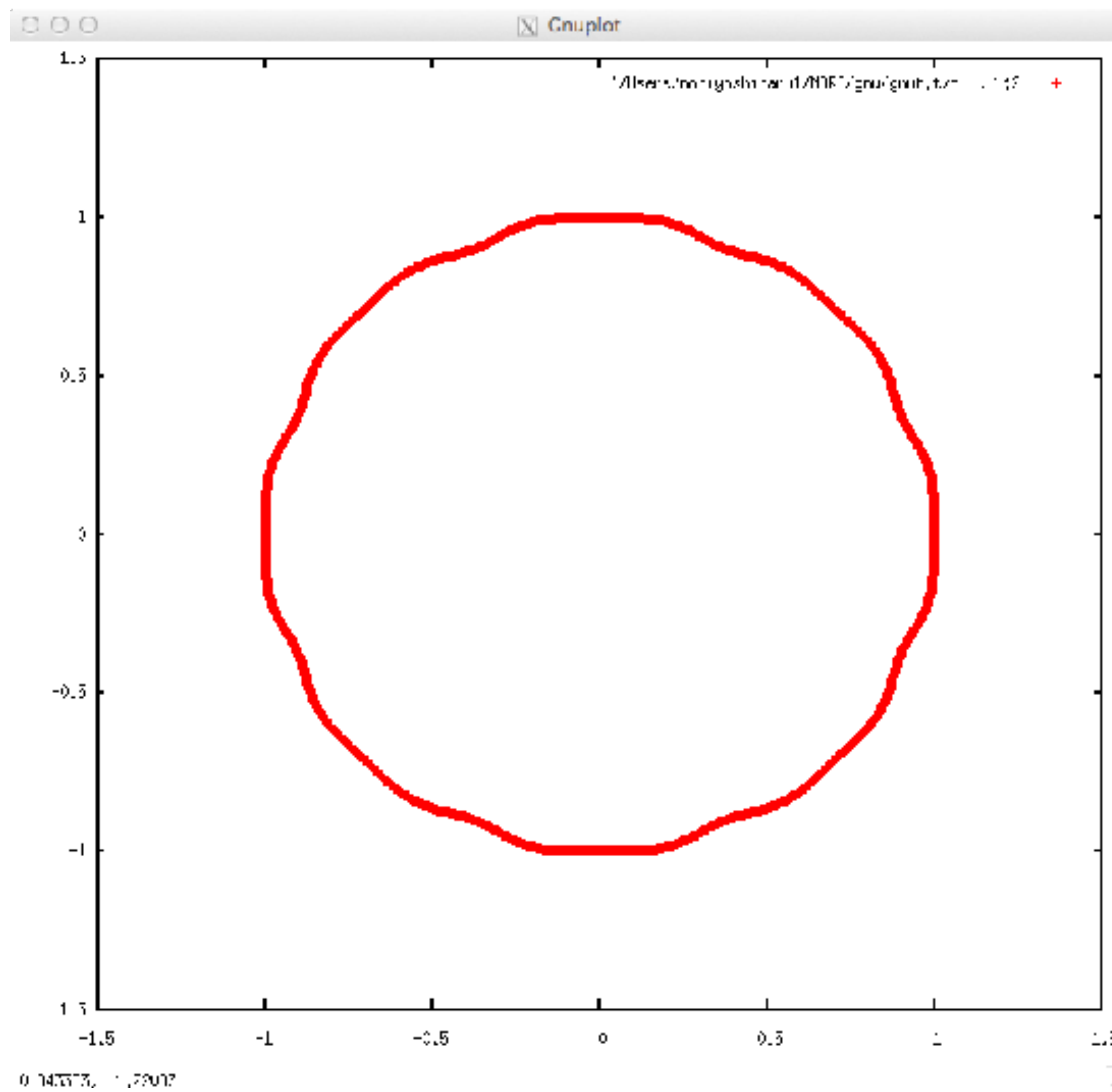
My study tool is **G4beamline**
Geant4 based MC code.

- particle interaction with materials,
- tracking in B/E fields by Runge-Kutta,
- particle decays

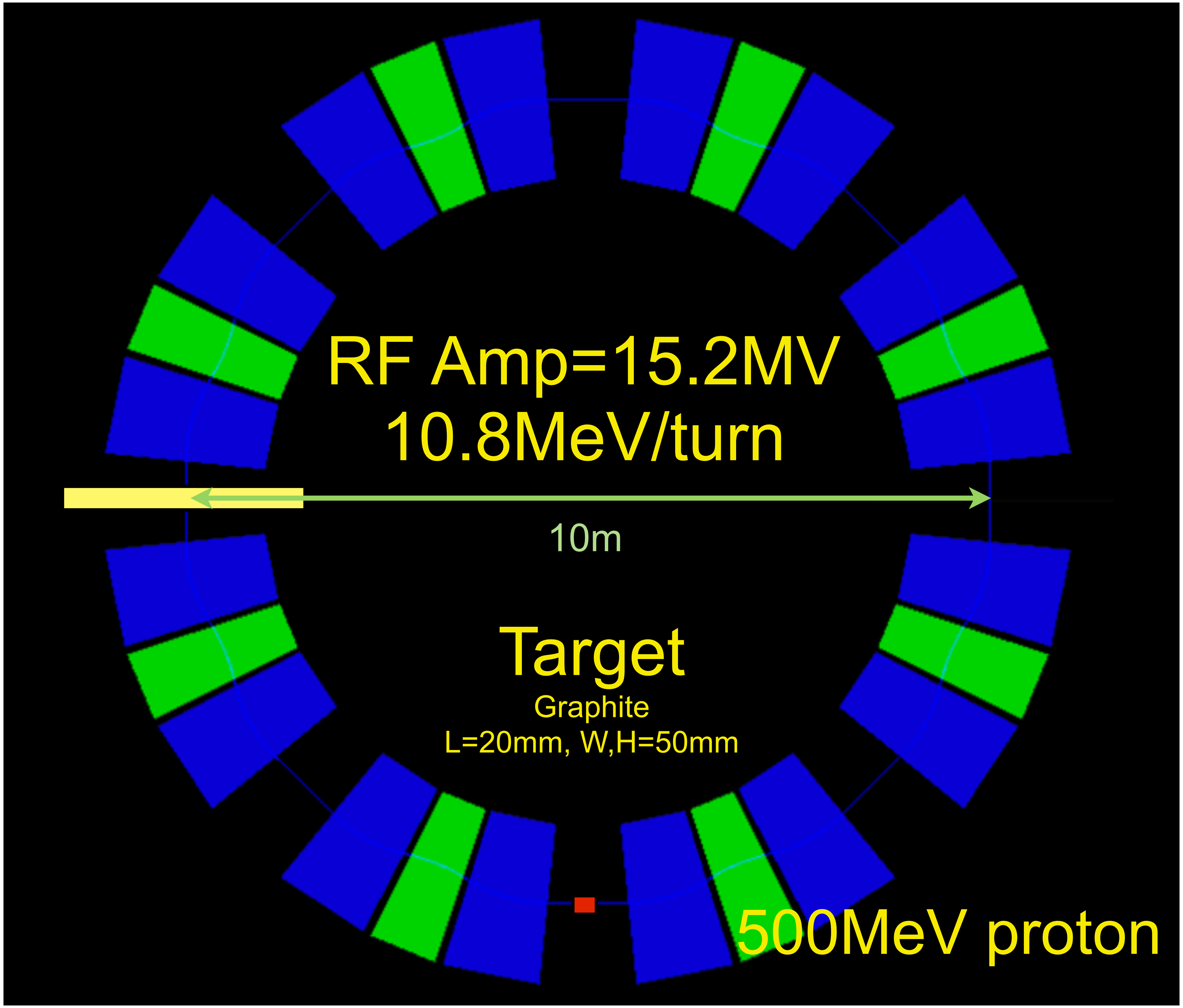
Lattice for SUPERIT

MERIT with proton -basic optics-

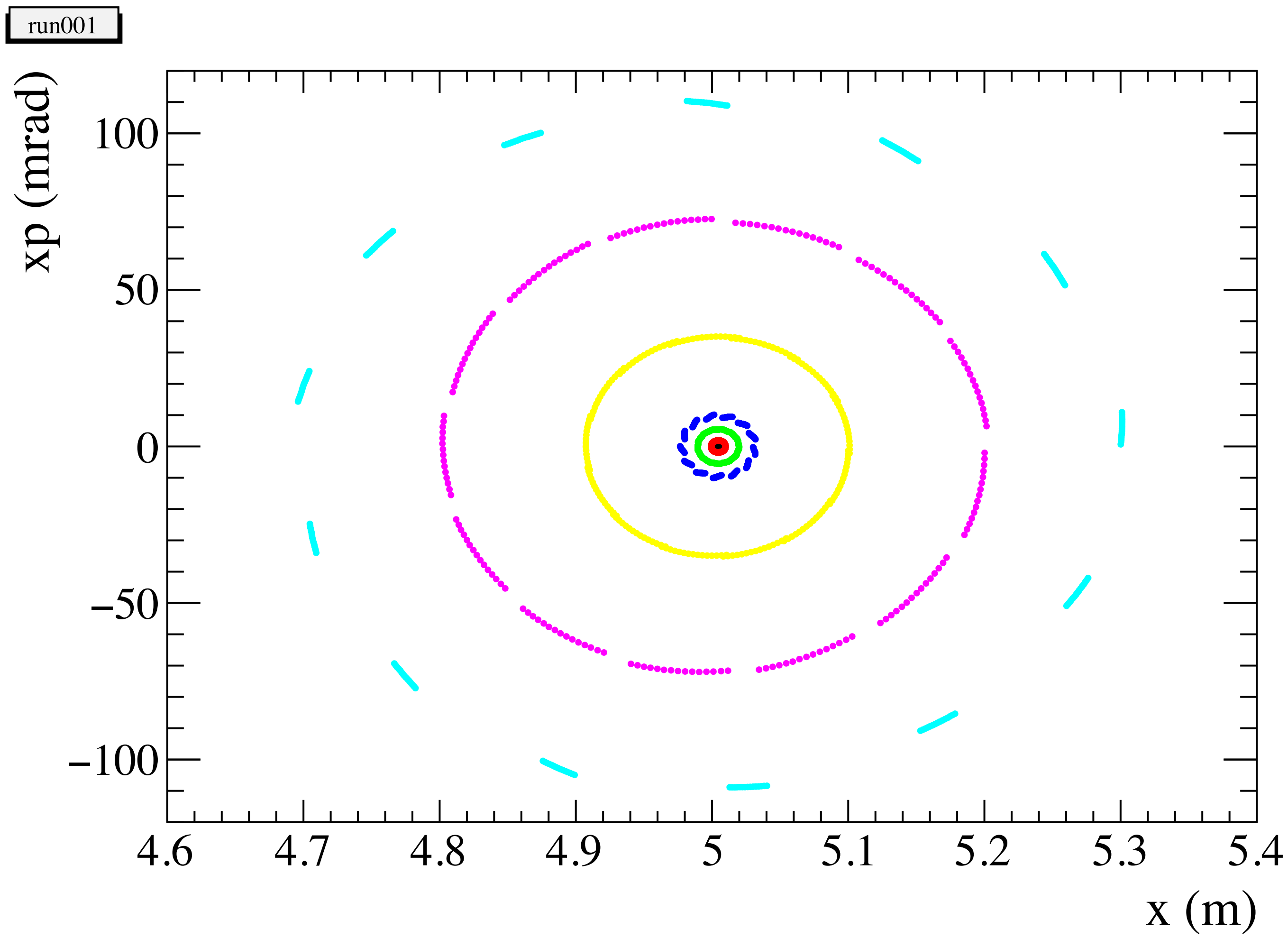
Ring configuration	H_FFAG
Energy range	500MeV-800MeV
Magnetic rigidity	3.633 -4.877Tm
Lattice	FDF
Average radius	5.044-5.5m
Magnetic field(F)	1.96-2.41T
Magnetic field(D)	1.71-2.11T
Number of cell	8
Packing factor	0.7
Magnet opening angles	
Focusing	0.2032
Defocusing	0.1432
gap	0.01732
Geometrical field index	2.4
F/D ratio	1.1
k	2.4
Qh	0.2188
Qv	0.1797
ρf	2.0233m(2.411T)
ρd	2.3157m(2.106T)

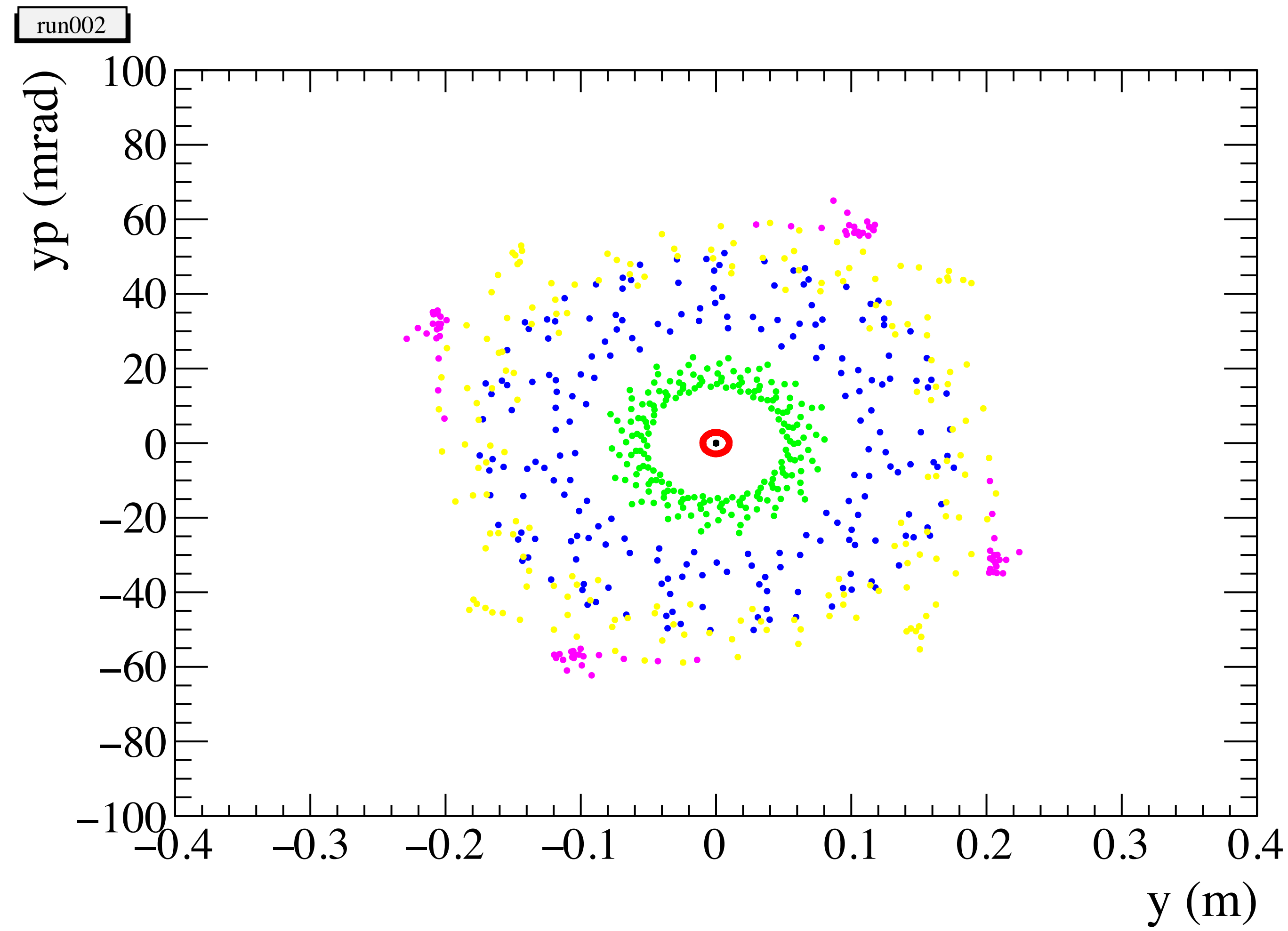


SUPERIT model in G4beamline

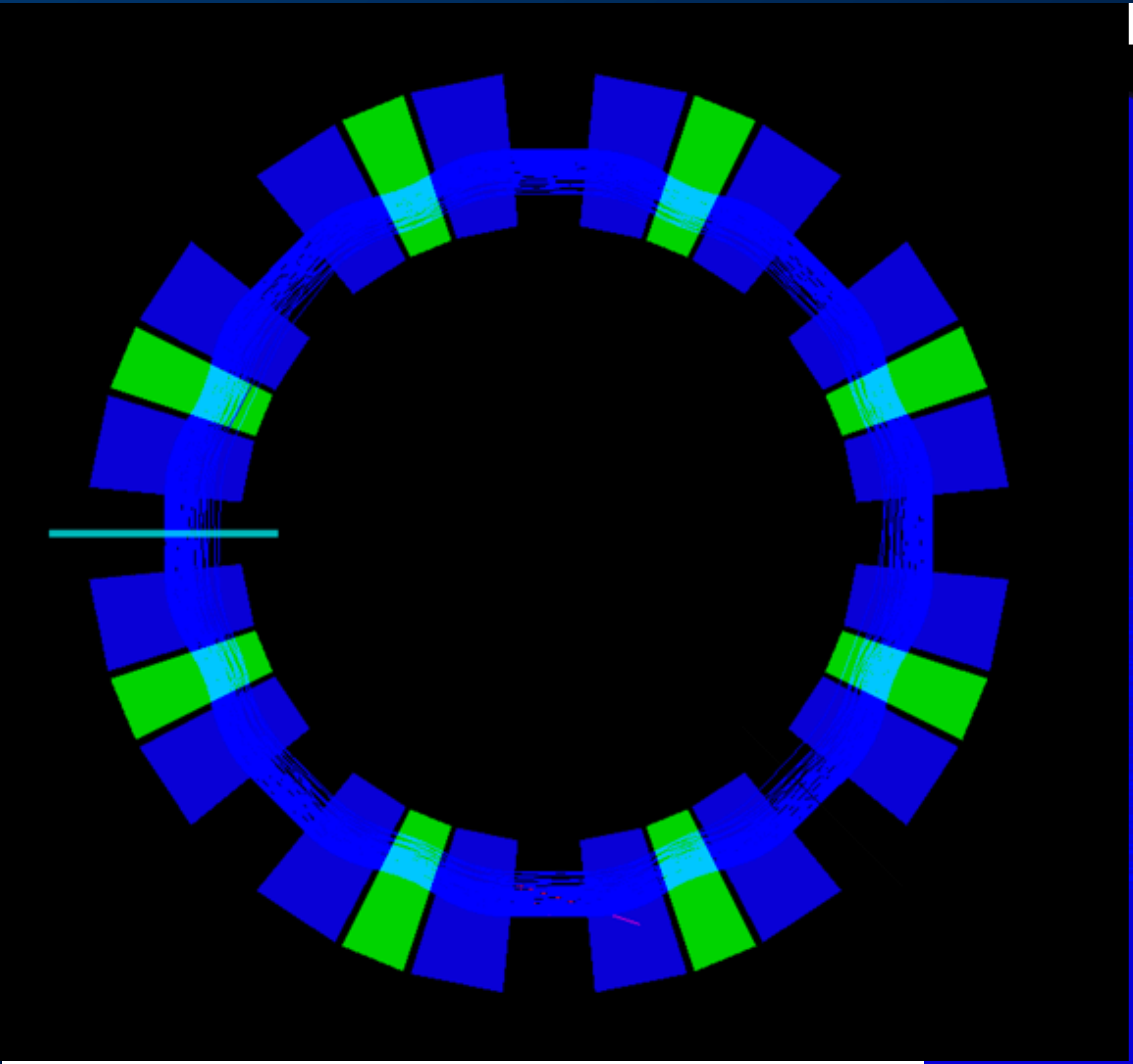


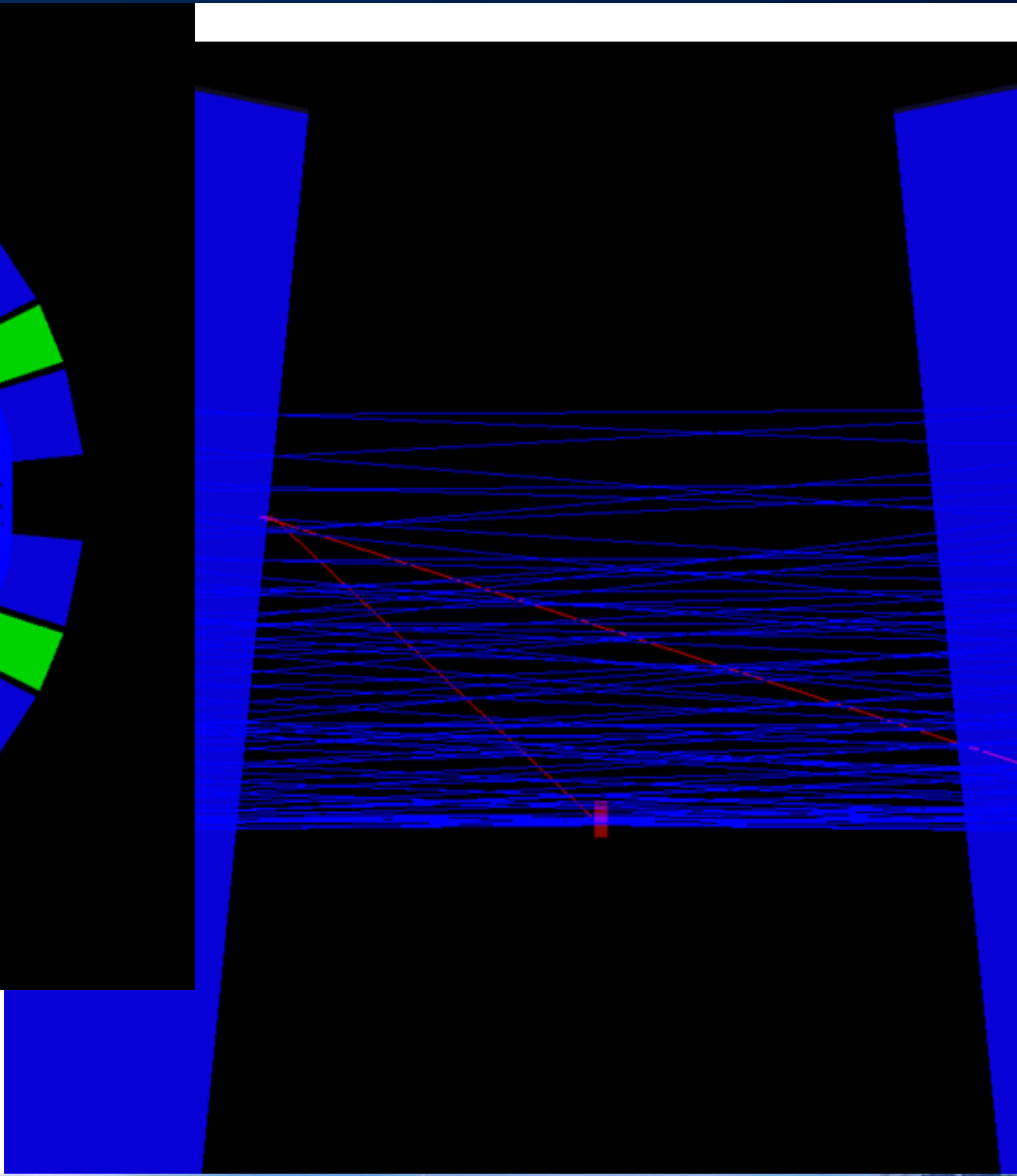
SUPERIT: Transverse acceptance



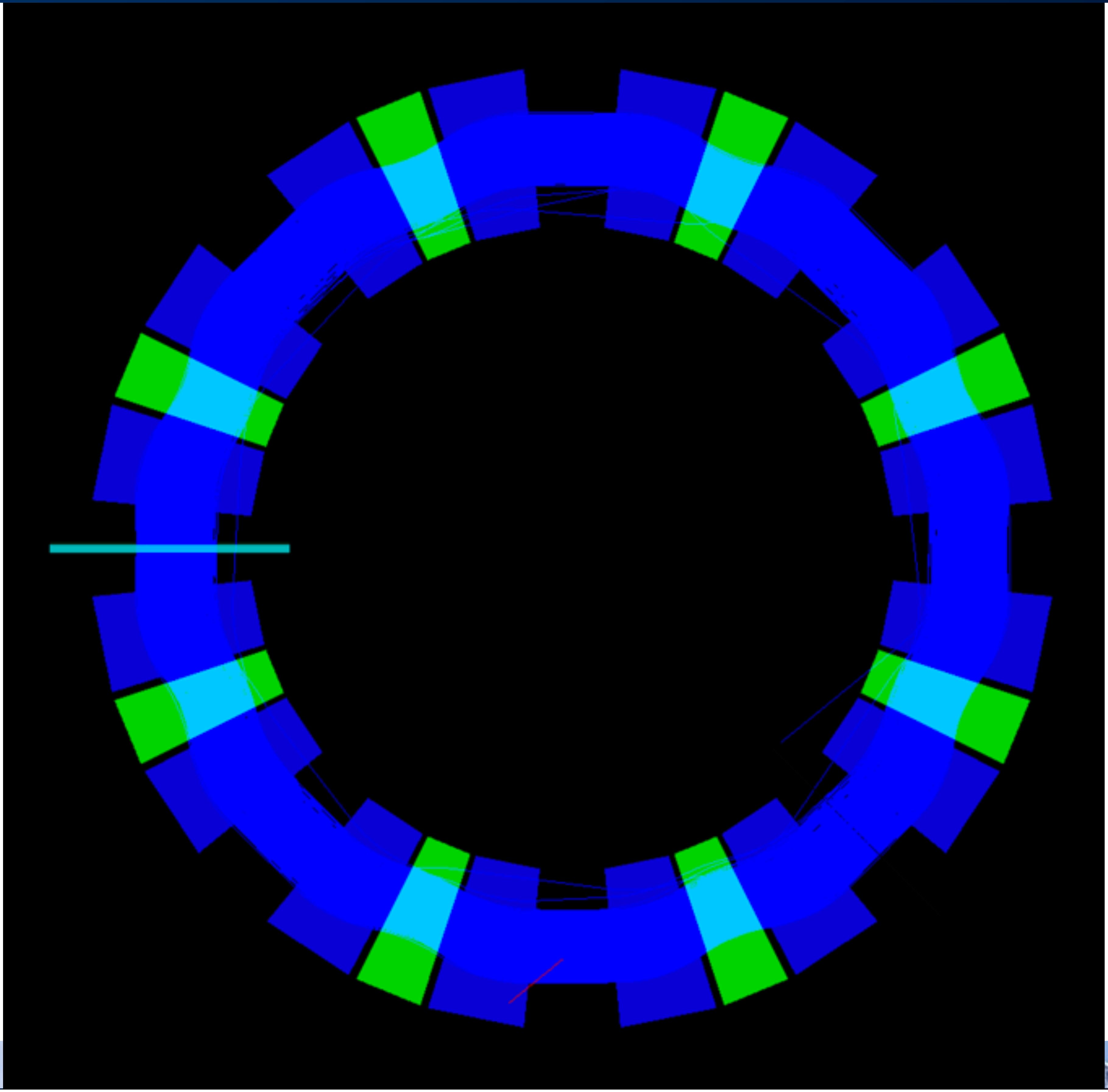


SUPERIT without RF

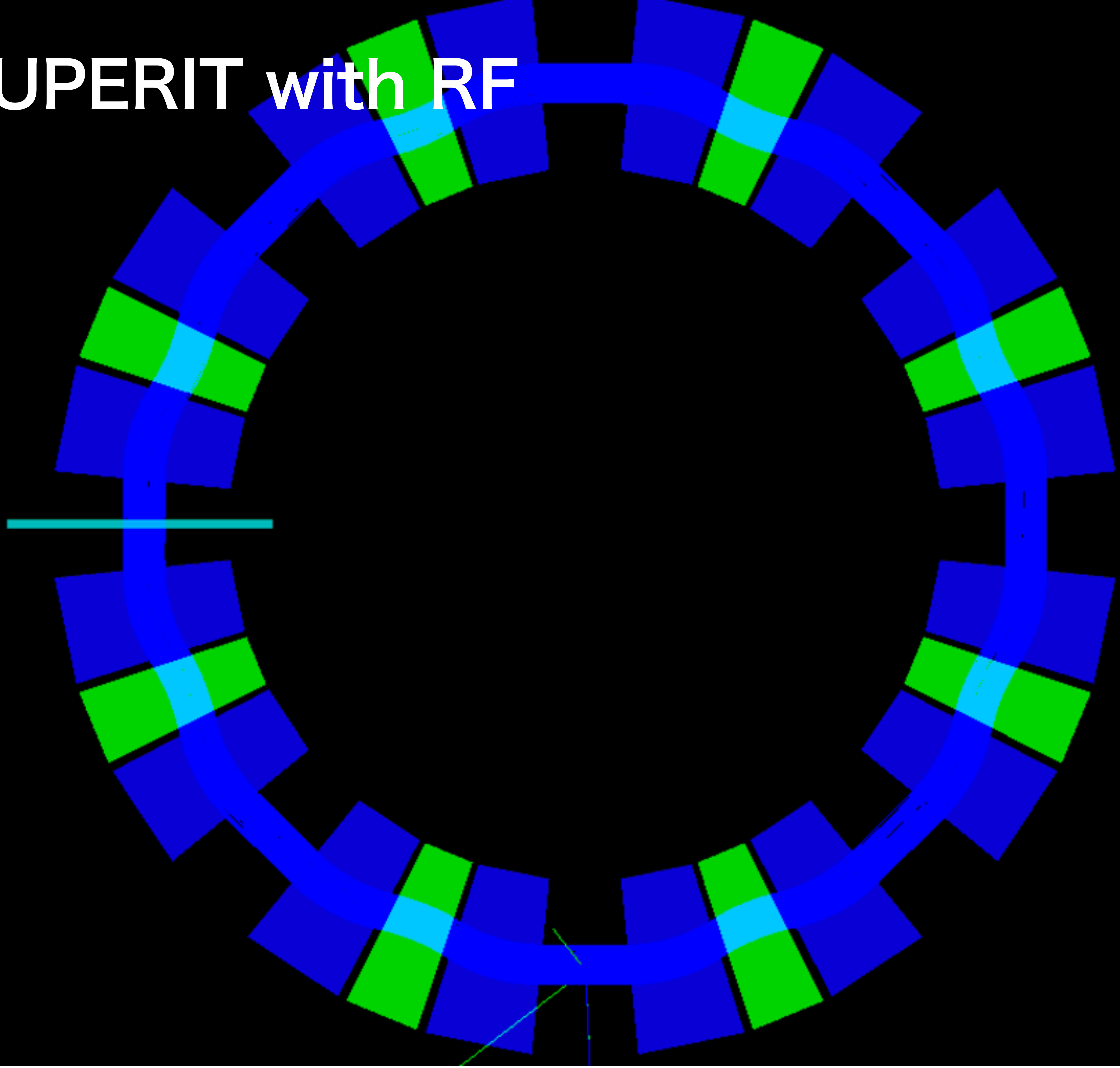




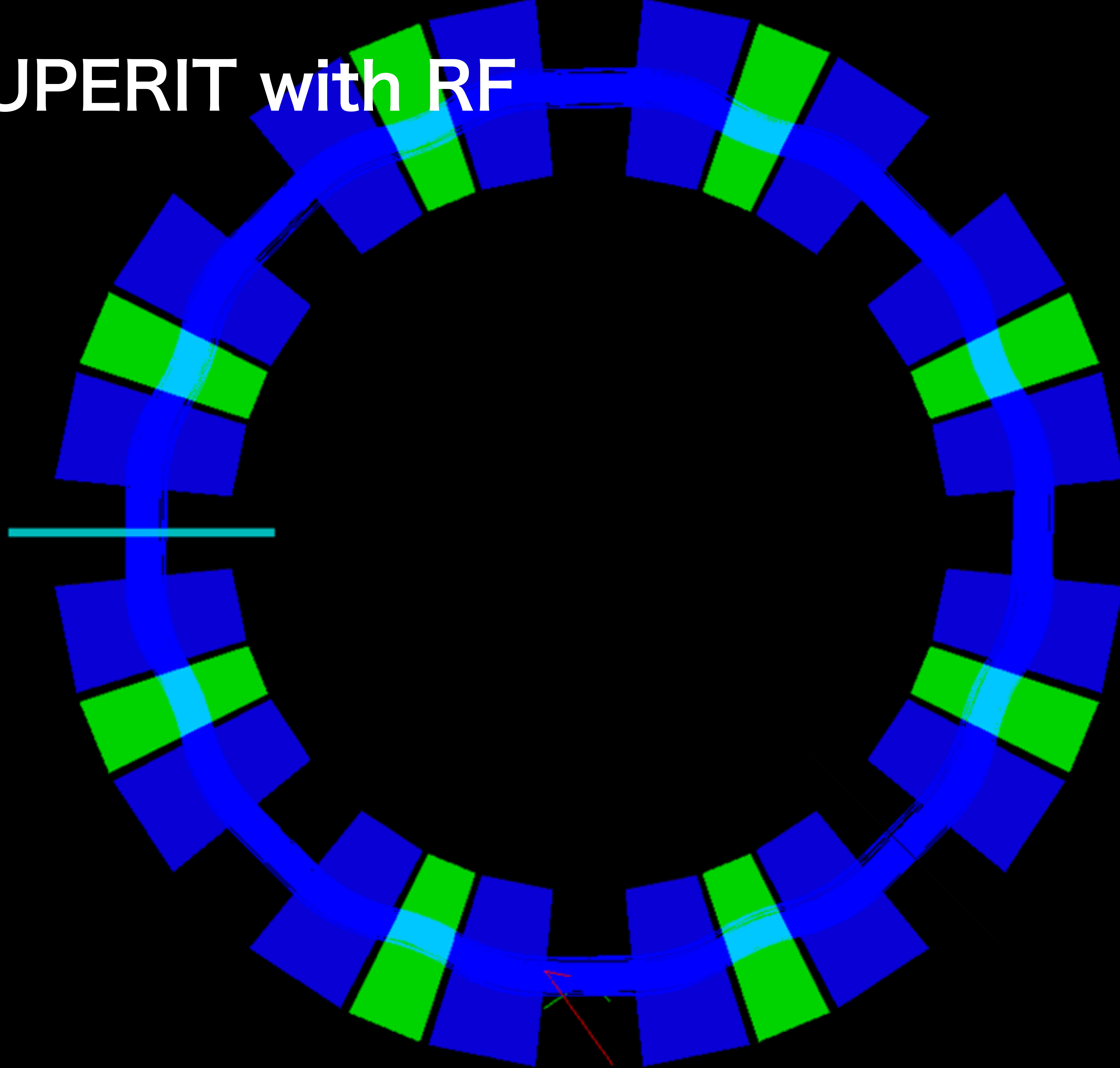
SUPERIT with RF



SUPERIT with RF



SUPERIT with RF



Conclusion: SUPERIT can work!