Muon production and acceleration

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Muon : fundamentals

- Muon
  - Fundamental particle : one of leptons, non-structure particle
    - Muon μ+μ- Collider : Lepton collider: √s > TeV , Less radiation loss (cf. electron)
    - Heavy mass : mμ/me ~ 200
    - Unstable τ ~2.2μs
    - Electro-weak interaction
      - Low energy EM force
      - High energy weak interaction

Request for muon acceleration

- High Energy Particle Physics
  - Muon collider
  - Radiography
  - Non-destructive inspection

Most interesting muon energy range

Pμ ~0.1-1GeV/c

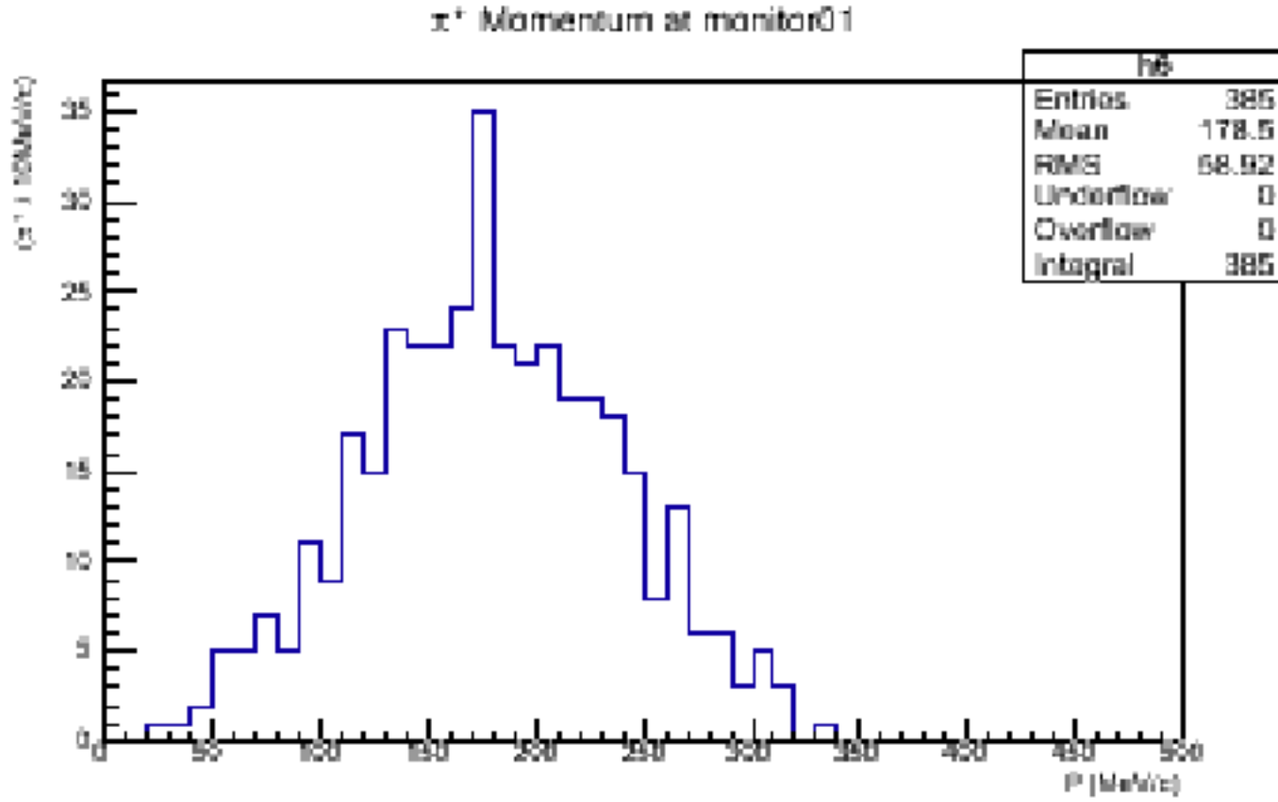
Muon production

- Way of muon production
  - π production
    - NΔ-resonance hadron-nucleus interaction
    - photo(γ)-production　Bremsstrahlung e+X
- e+($\sqrt{s}$>2mμ) + X → e+ e- → μ+μ- pair
  - positron :(Elab=44GeV)

NΔ-resonance : most efficient

NΔ resonance

- Relative low energy : cm-energy √s ~ 2.1GeV (N>320MeV)
  - p_π ~ 200MeV/c
- Large emittance : ε > 1000mm.mrad
- Large momentum spread : Δp/p ~ >+-10%



d(500MeV/u)+ Li

π-(μ-) production

- Destruction of π-
  - π- + X $\rightarrow$ π0 + X* : charge-exchange
  - Thick target is difficult to use.
  - ERIT(Energy Recovery Internal Target) with thin target becomes essential to produce intense π-(μ-).

π (μ) production

- π production threshold energy ~300MeV/u
- Stopping power

Thick target

$$\varepsilon = \frac{N_A}{A}\int_{E_0}^{E_{th}} \frac{\sigma(E)}{S(E)} dE.$$

$\sigma(E)$: *cross section*, $S(E)$: *stopping power*

η : *statistical weight for specific reaction*

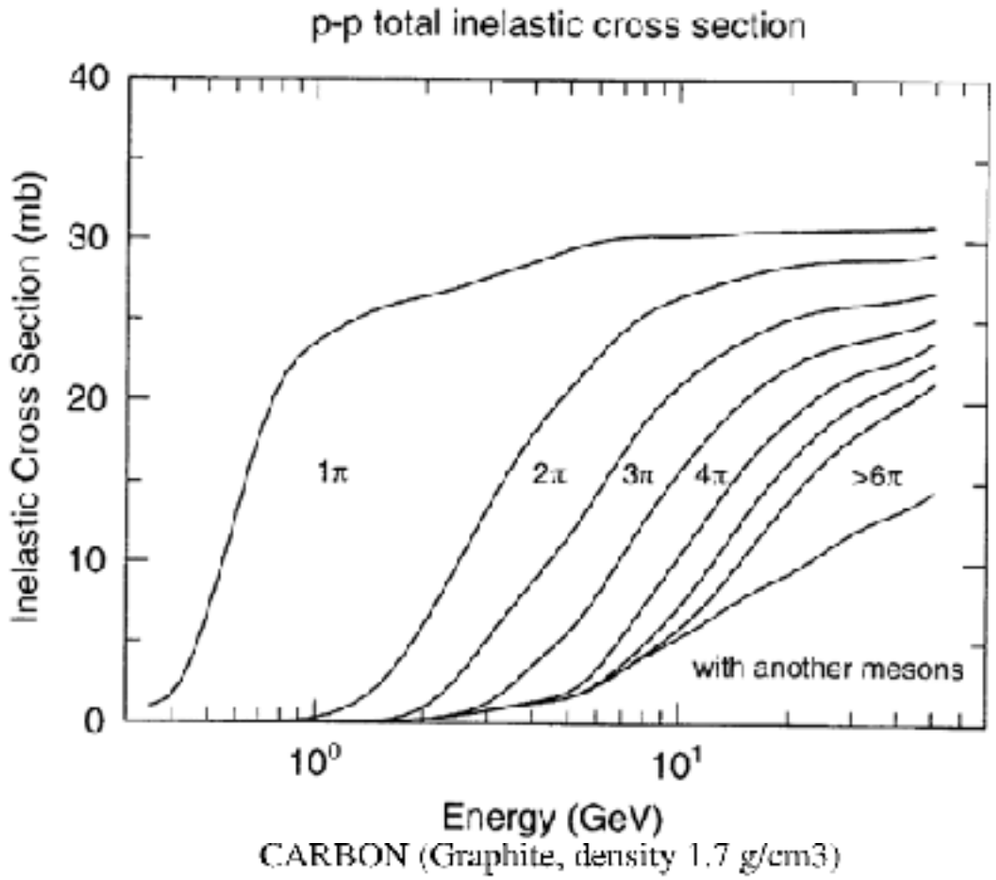
E_{th} : *threshold energy*, E_0 : *beam energy*

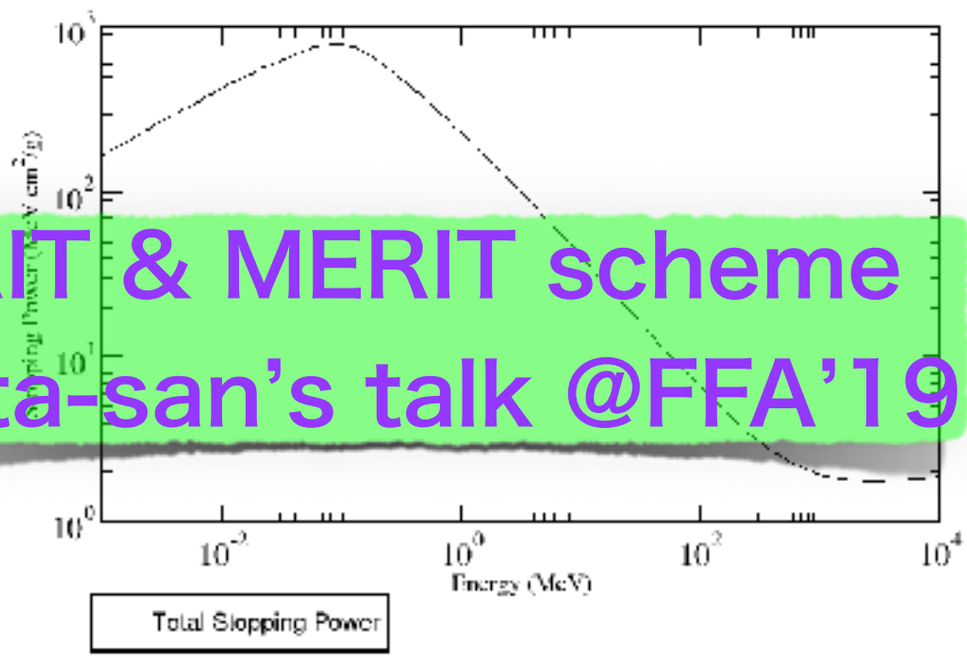
N_A : *Avogadro number*, A : *Atomic number*.

ε ~2×10^{-2} for Carbon

Thin target

ERIT is 50 times more efficient!





ERIT & MERIT scheme
Okita-san's talk @FFA'19

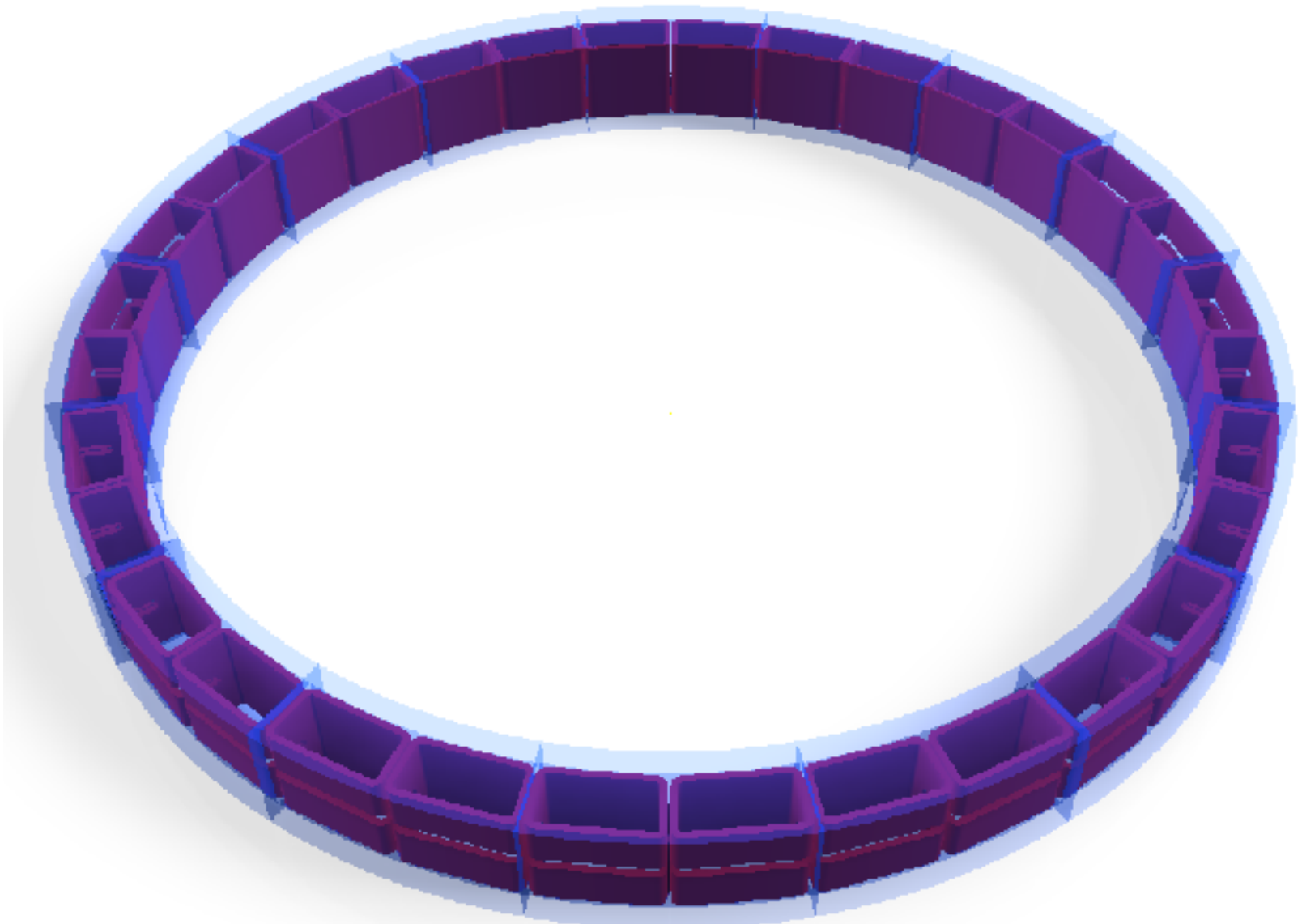
Acceleration of π (μ) particles

- Acceleration combined with internal target π (μ) production system : new approach.
    - Accelerator possible specifications
        - Large acceptance
            - Ax >1,000mm.mrad, $\Delta p/p$ > +-20%
        - Quick acceleration
            - E > 2MeV/m
- HFFA or VFFA
- Combination with ERIT system is possible.

HFFA

air_core type of magnet

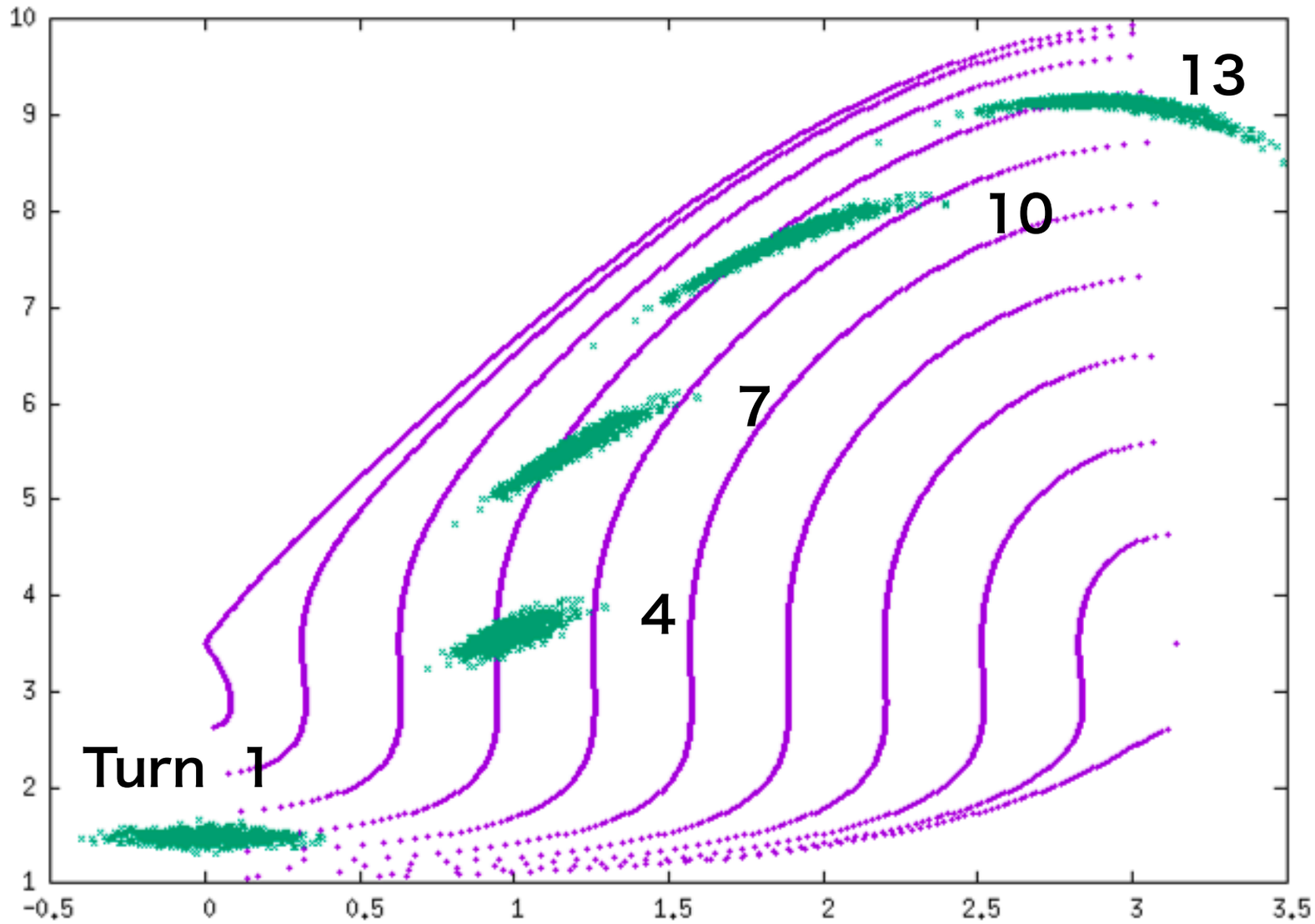
- B>4T
- Also useful for 2_way FFA collider & MERIT ring.
- Details →　“tomorrow”



H_FFA

k=9, γ s=3.5,Vrf=78MV(2.5MeV/m)

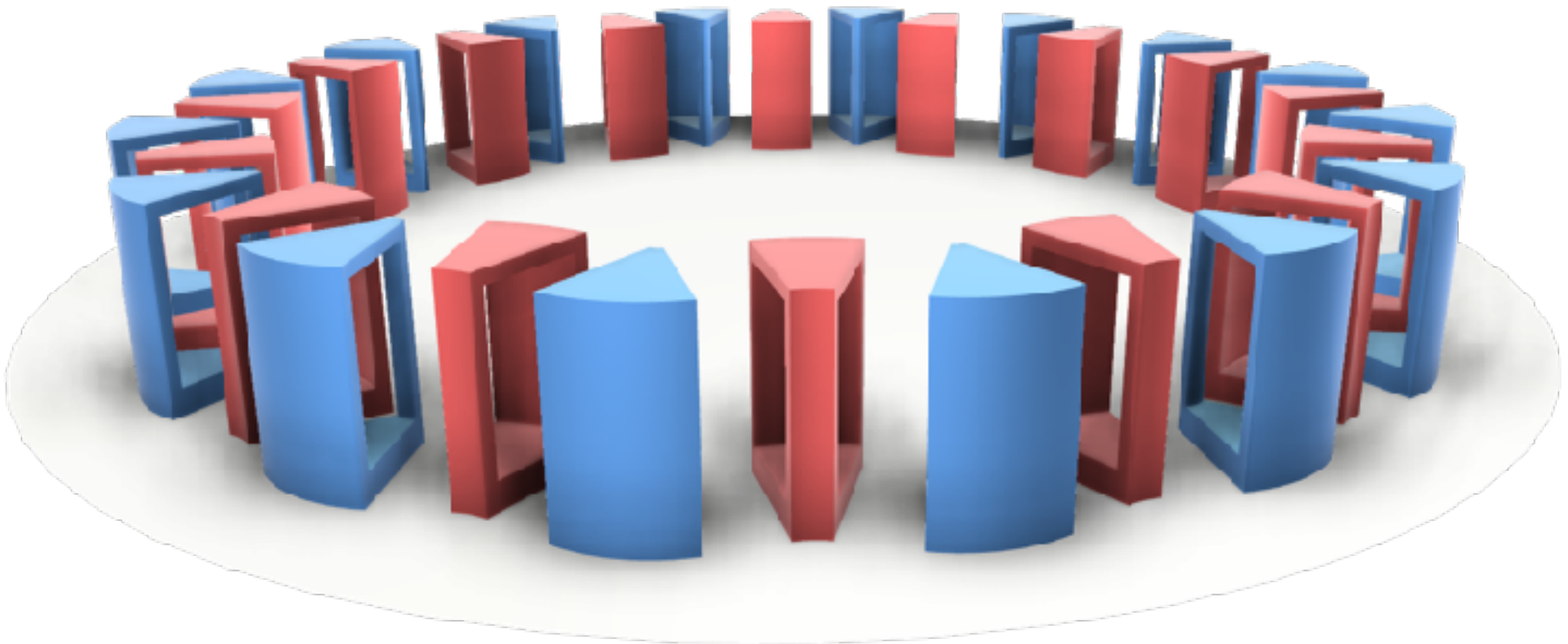
```
0.104     0.05      0.                    ;rest mass(GeV), kinetic energy (GeV), phase_0(rad)
1         15        3                     ;number of cells,  turn number
5.4       5.4       ;ban_f, bang_d (degree)
1.        0.2       9.        0.04        ;R_0(m), ro_f0(m), k0(m-1), l_f(m)
0.01      0.0       0.01      0.0         0.0         0.0 ;x(m),xp(rAD),y(m),yp(rad)
1         25        25        ;Stability(o)orTrack(1) l_num m_num
1000                          ;number of particles
1.        3.5       0.75      ;harm, gams, RF_V
0.25      0.01                ;sig_fi_0(rad)   sig_kine_0(GeV)
!muon   F_D triplet
```



Vertical scaling V_FFA

- Geometrical field index: m=2 m^{-1}
- On-γt acceleration(serpentine) γs=5
- Energy range 100MeV - 1 GeV
- Lattice FD sector singlet
- Cell number 16cells
- **Vrf** **46MV (2MeV/m)**
- PF 0.88
- **R** **3.6m**
- Bmax 5.T

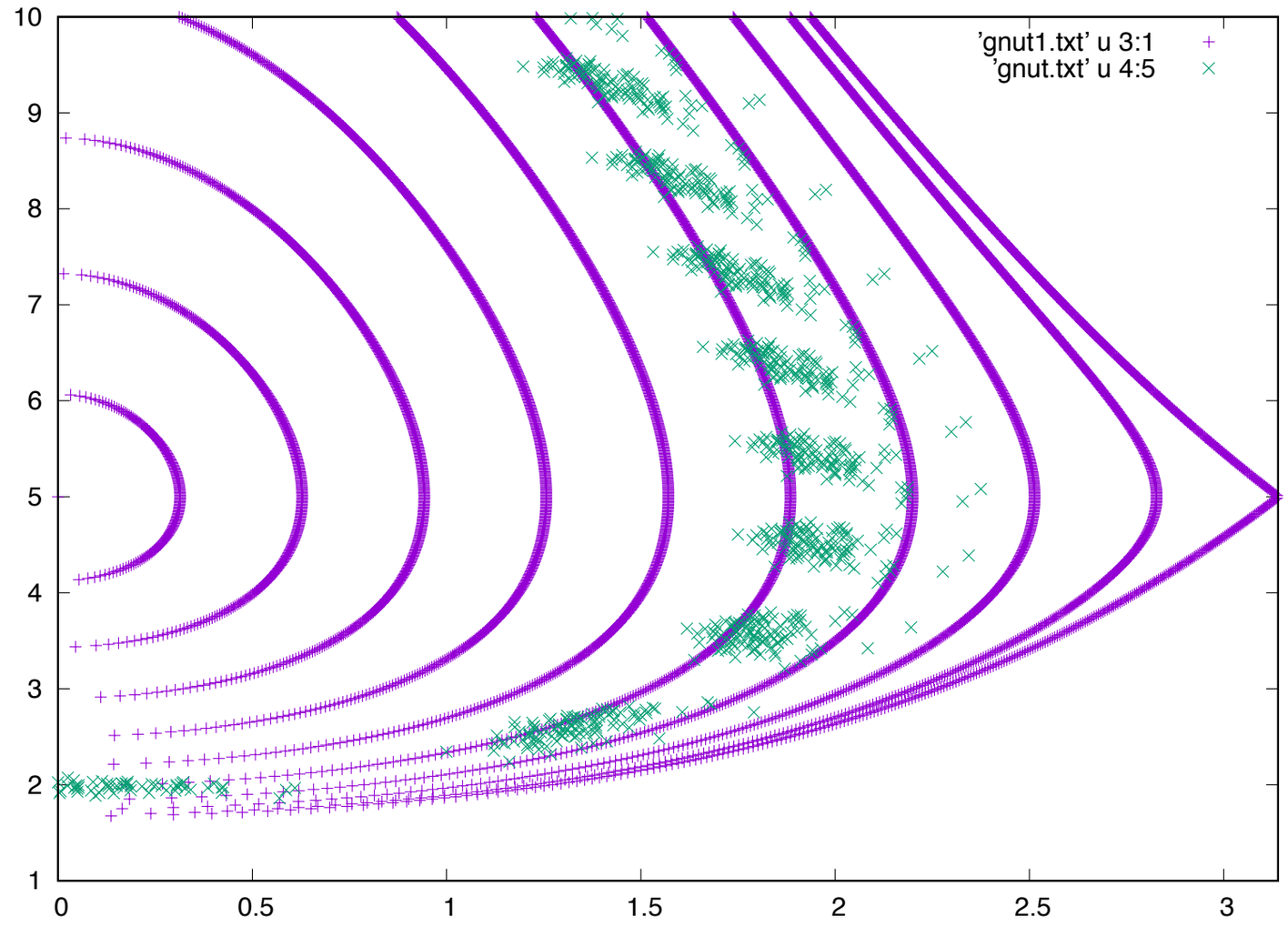
Vertical scaling V_FFA



V_FFA

m=2(m^{-1}), γ s=5, Vrf=46MV(2MeV/m)

```
mori-yoshiharu-no-MacBook-Air-2:longitudinal_motion moriyoshiharu1$ ./beam_track_vffag_ln.exe
  rest mass of projectile particle(GeV)                 Kinetic energy(GeV)  Initial phase(rad)
  0.10404000000000000       0.10000000000000001       0.0000000000000000
  number of cells, number of turns
           1          10
 bang_f,bang_d (deg)
   5.4000000000000004        5.4000000000000004
 R_0  ro_f0 mk0 l_f
   1.0000000000000000       0.20000000000000001       2.0000000000000000        4.0000000000000001E-002
  initial conditions                                  x_i  xx_i  y_i  yy_i  z_i  zz_i
   1.0000000000000000E-002   0.0000000000000000       1.0000000000000000E-002   0.0000000000000000        0.0000000000000000        0.0000000000000000
  stability(0) or track(1)                              l_number(25)  m_number(25)
           1          25          25
 number of particle
         100
 harmonics  gam_s                                      RF_voltage(/rest mass)
   2.0000000000000000        5.0000000000000000        1.0000000000000000
 initial distribution                                  sig_fi_0(rad)   sig_kine_0(GeV)
  0.50000000000000000       1.0000000000000000E-002
```



Summary

- Acceleration of muons with H_FFA or V_FFA accelerator looks interesting and efficient using internal π (μ) source(target).
    - No beam transport for π -μ.
    - Combined with ERIT scheme, 600 times more intense μ beam could be obtained
- H_FFA
    - Straight-forward design
        - Large acceptance
        - More Vrf voltage
        - Air core magnet seems interesting.
- V_FFA
    - Easier acceleration for muon → less rf voltage.
    - Careful design works must be necessary.
        - Acceptance : especially transverse direction?
        - Magnet design : fringe field → Adachi-san talk in this session