Simulation Study for RFFAG Decay Rings

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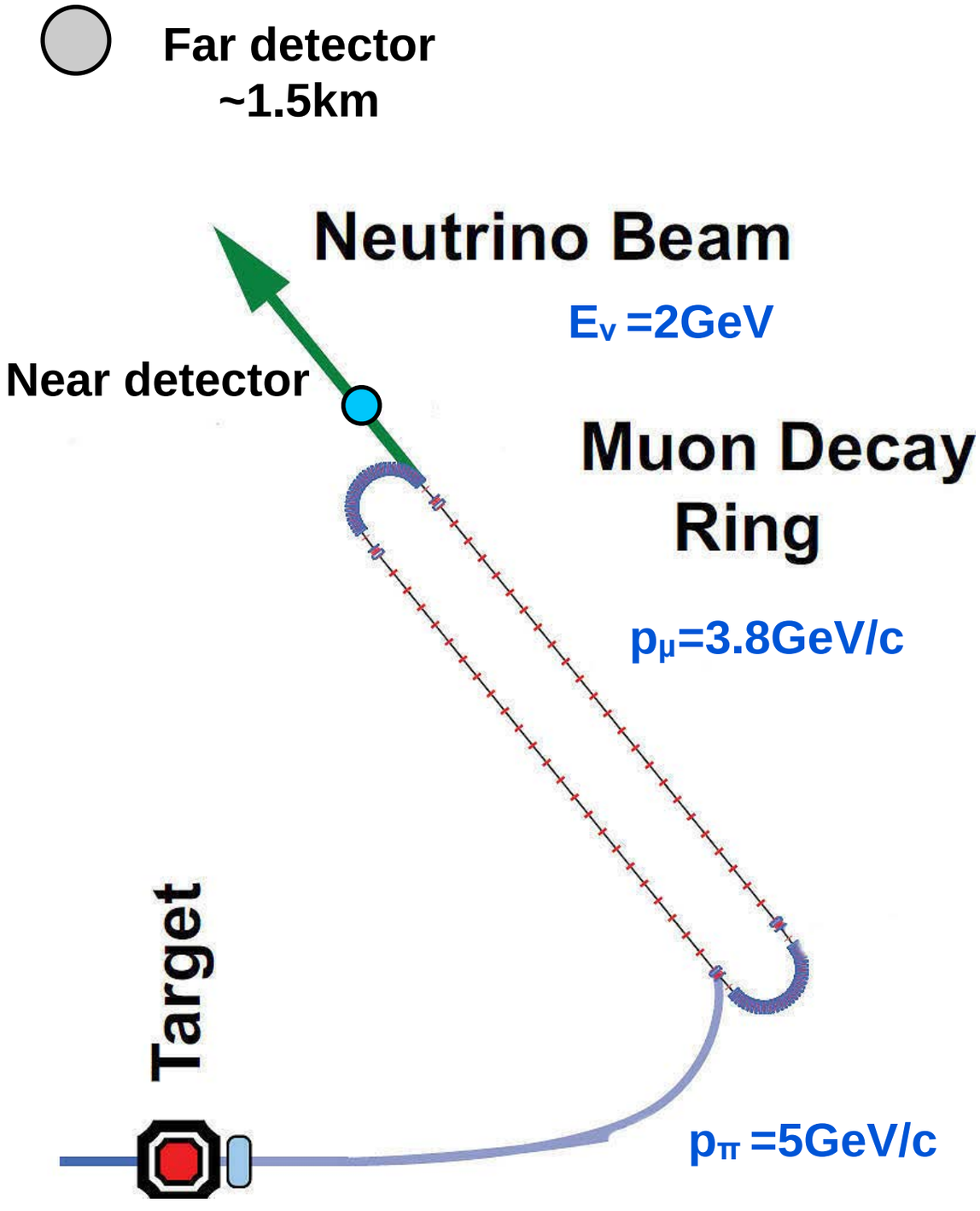
25+5 min

Contents

- Review of 2.0GeV RFFAG ring study
- Status and plan for the 3.8GeV/c RFFAG ring study
- Acceptance of the decay ring for muon from pion decay
- Summary

vSTORM

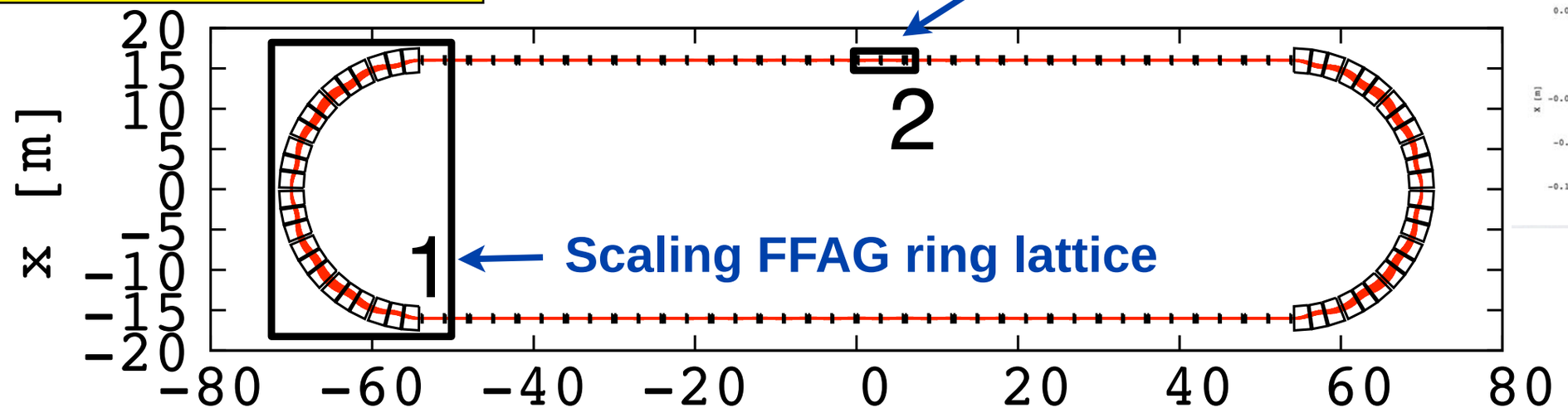
- A new LoI of a short-baseline neutrino experiment has been submitted to FNAL-PAC.
  - Physics:
    - study of sterile neutrinos
    - precise measurement of neutrino-nucleon scattering cross sections.
- A production of neutrino beams from a muon storage ring without any cooling section.
- <u>For the muon decay ring</u>,
    - large transverse acceptance
    - large momentum acceptance
  - are required to increase the intensity of the ν beam.
  - Two candidates
    - FODO racetrack
    - **FFAG racetrack**

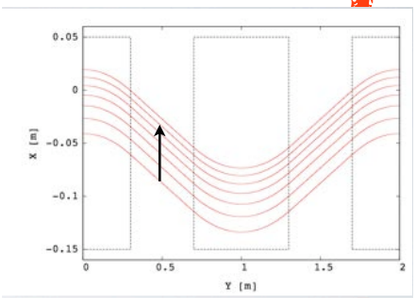


Study of Racetrack FFAGs for vSTORM

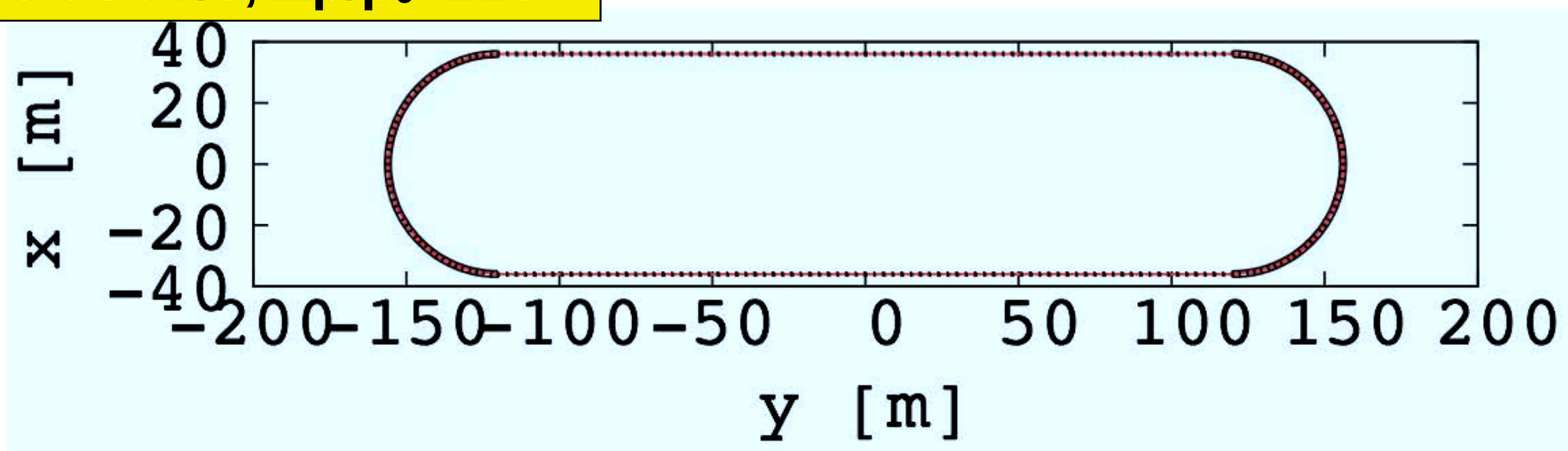
- J.B.Lagrange and Y.Mori proposed two racetrack FFAG for the decay ring.

E_μ=2GeV, $\Delta p/p_0$=±16%



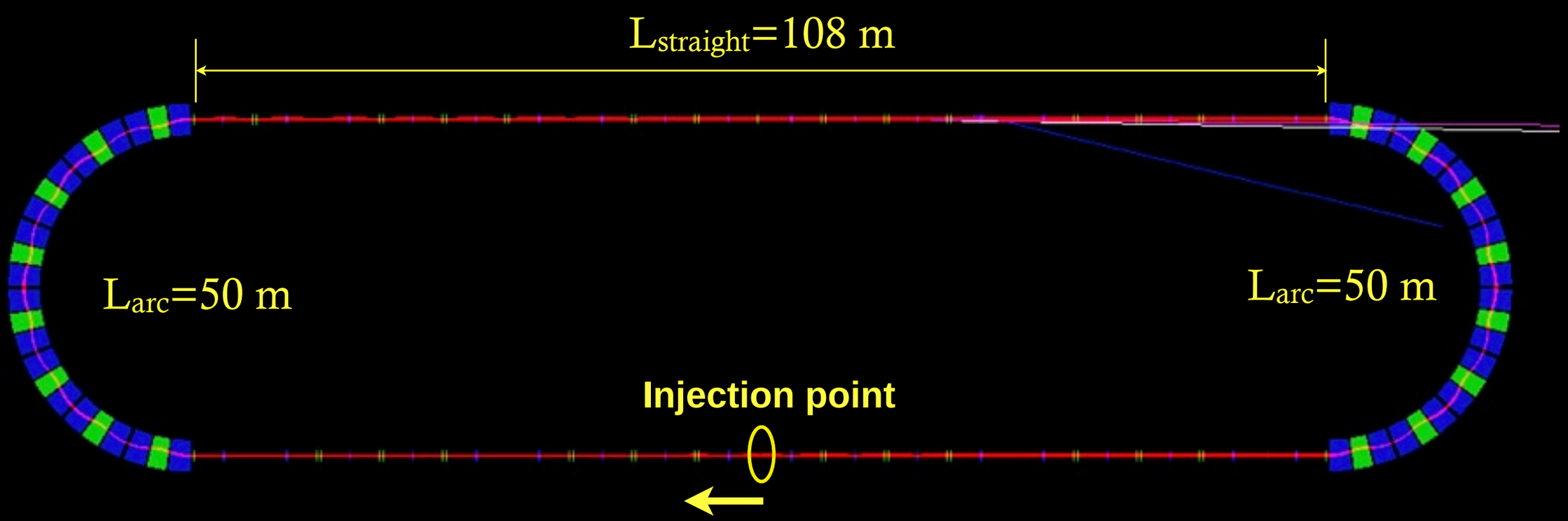


p_μ=3.8GeV/c, $\Delta p/p_0$=±16% in the vSTORM LoI



- They studied performance of these FFAGs by their original tracking code, which cannot study decay of muon.

Tracking of JB's 2GeV Ring by g4beamline



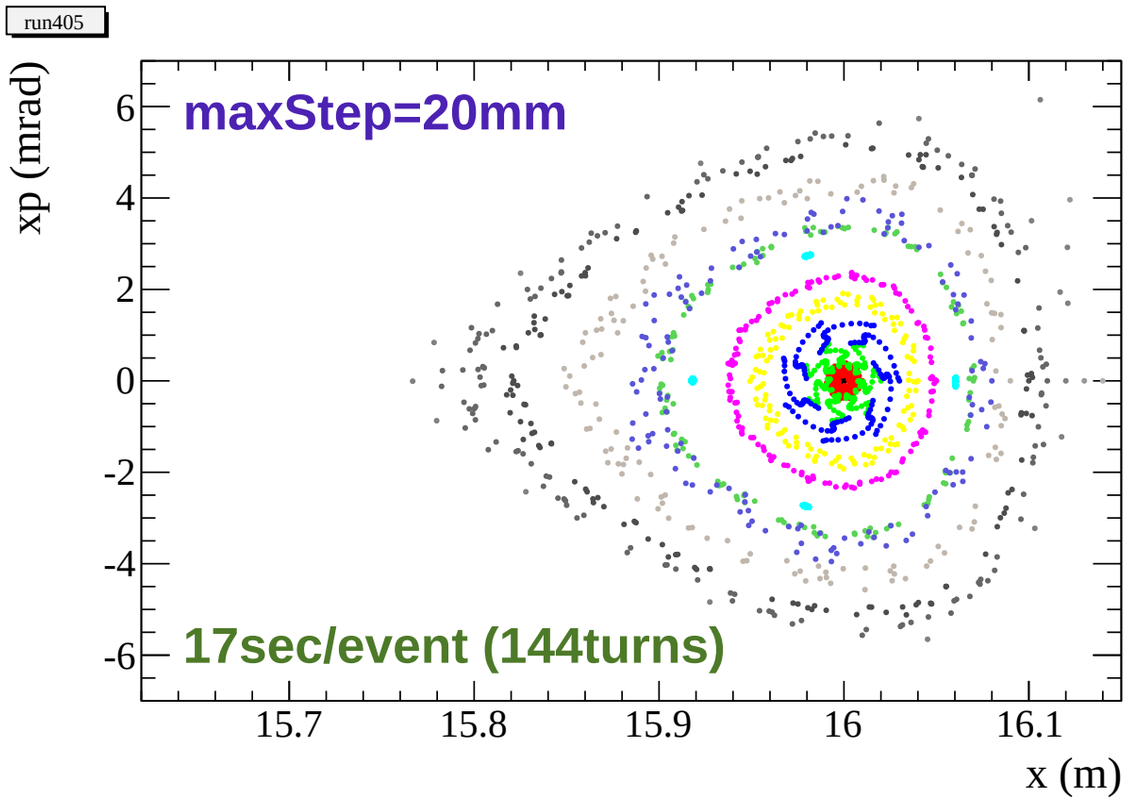
red: μ^- blue:e^- white:ν_e magenta:anti-ν_μ

Study of Racetrack FFAGs with g4beamline

- I study production of neutrino beam from the racetrack FFAGs for vSTORM using g4beamline.
- The g4beamline
  - is very useful and easy to use. It is a geant4 based code.
    - particle interaction with materials,
    - tracking in magnetic fields,
    - particle decays
  - But it uses Runge-Kutta for tracking, not-symplectic
    - not the best code to get accurate tracking result, in particular tracking in a very long channel.
    - tiny step size makes better tracking results, but needs long running time.
- with 2GeV RFFAG ring
  - I compared g4beamline's tracking results with JB's results to get a reasonable step size.
  - Then, I studied neutrino beam production from the FFAGs.

Step size effects on the tracking

Horizontal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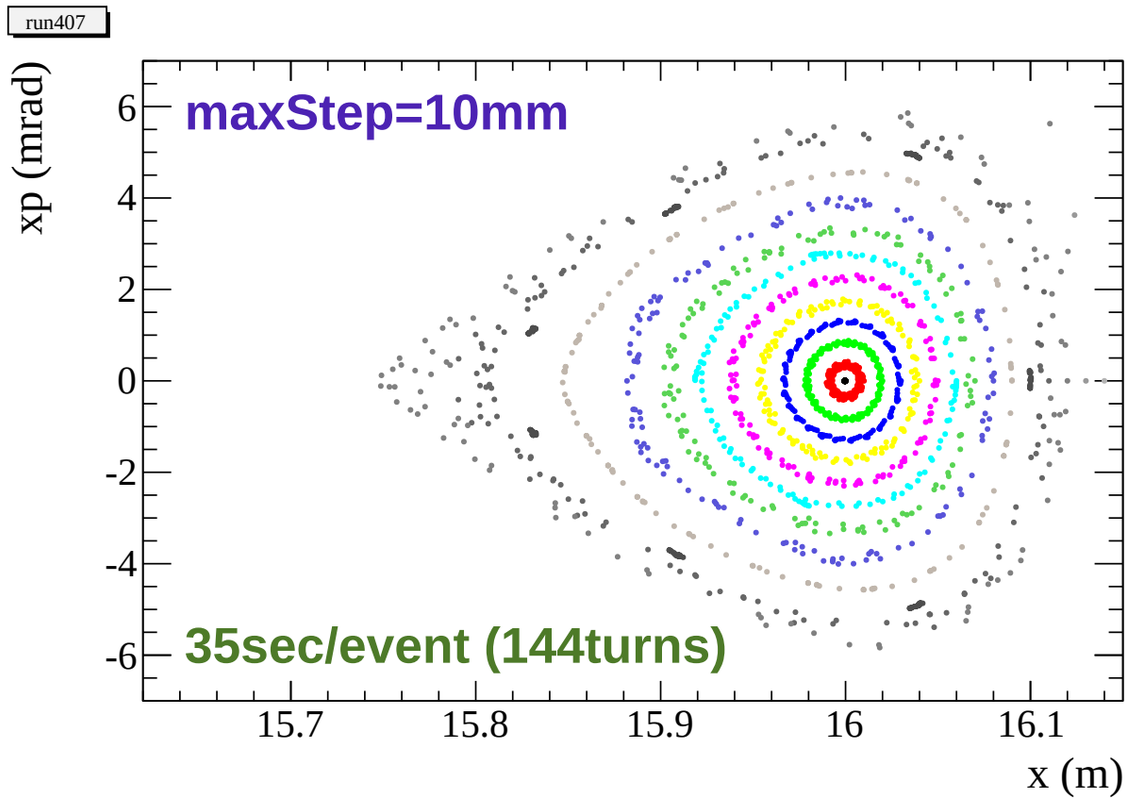
xp (mrad)
x (m)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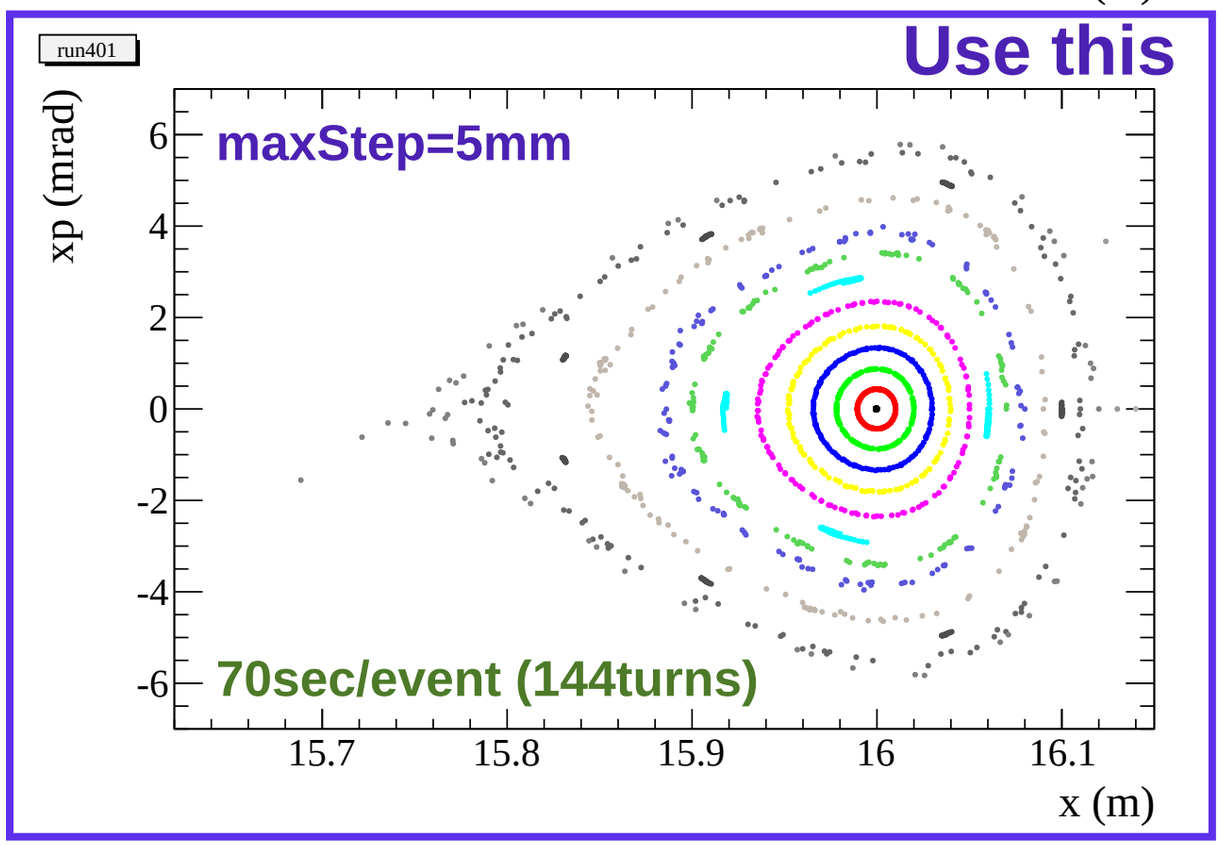
xp (mrad)
x (m)


Use this
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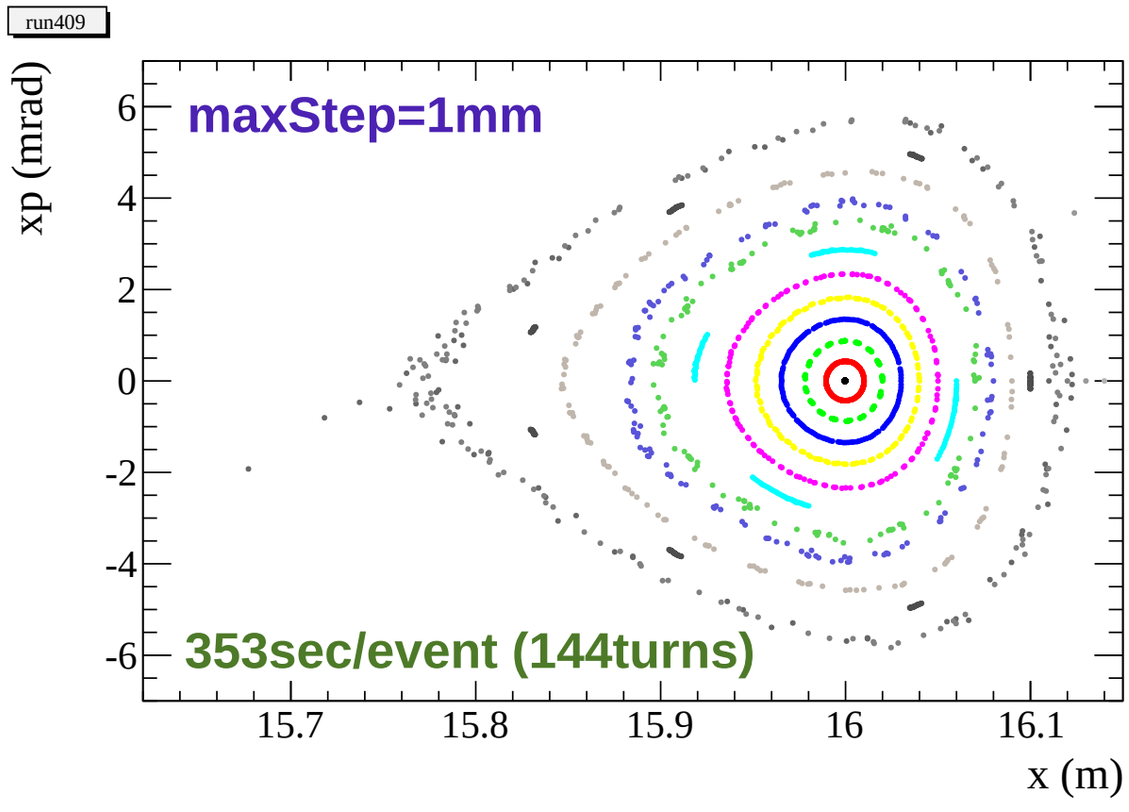
x (m)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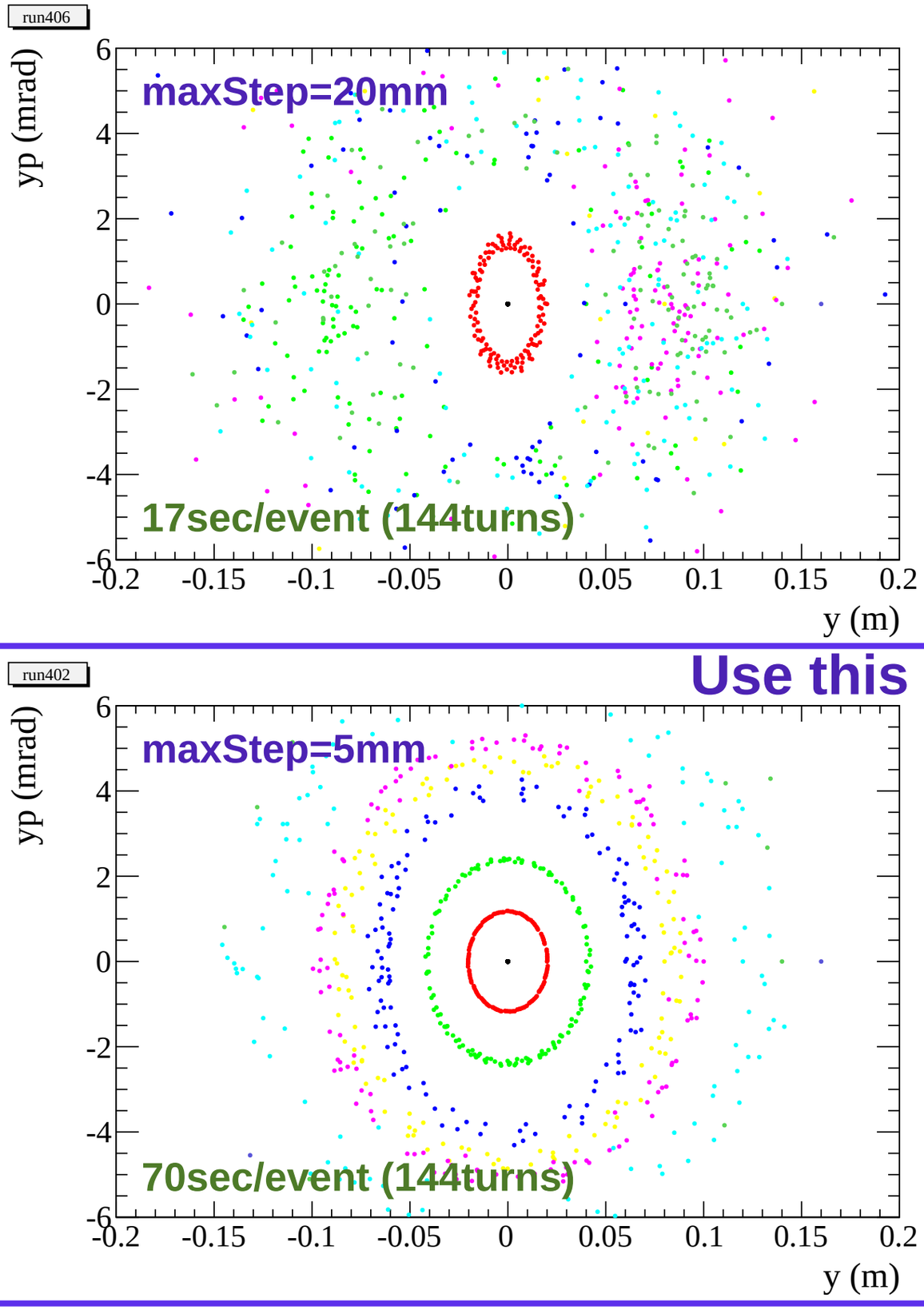
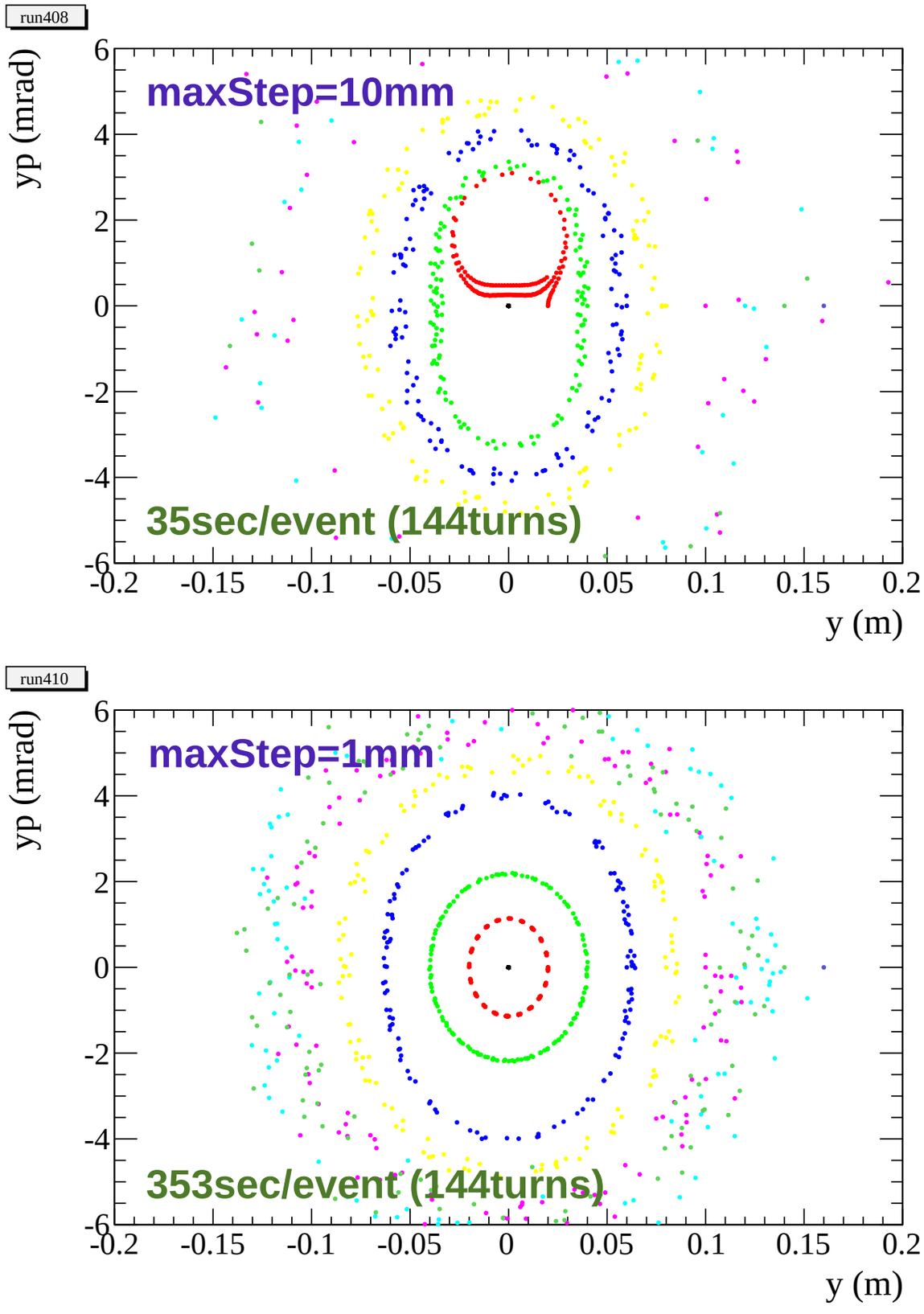
xp (mrad)
x (m)

Vertical

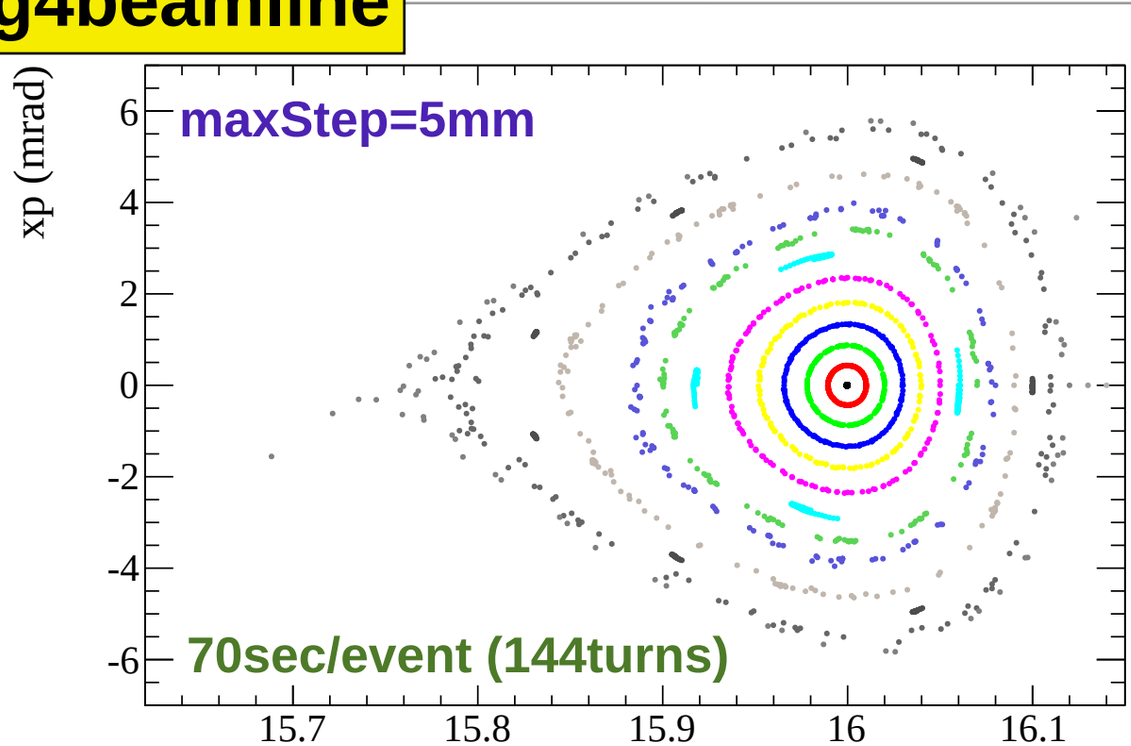


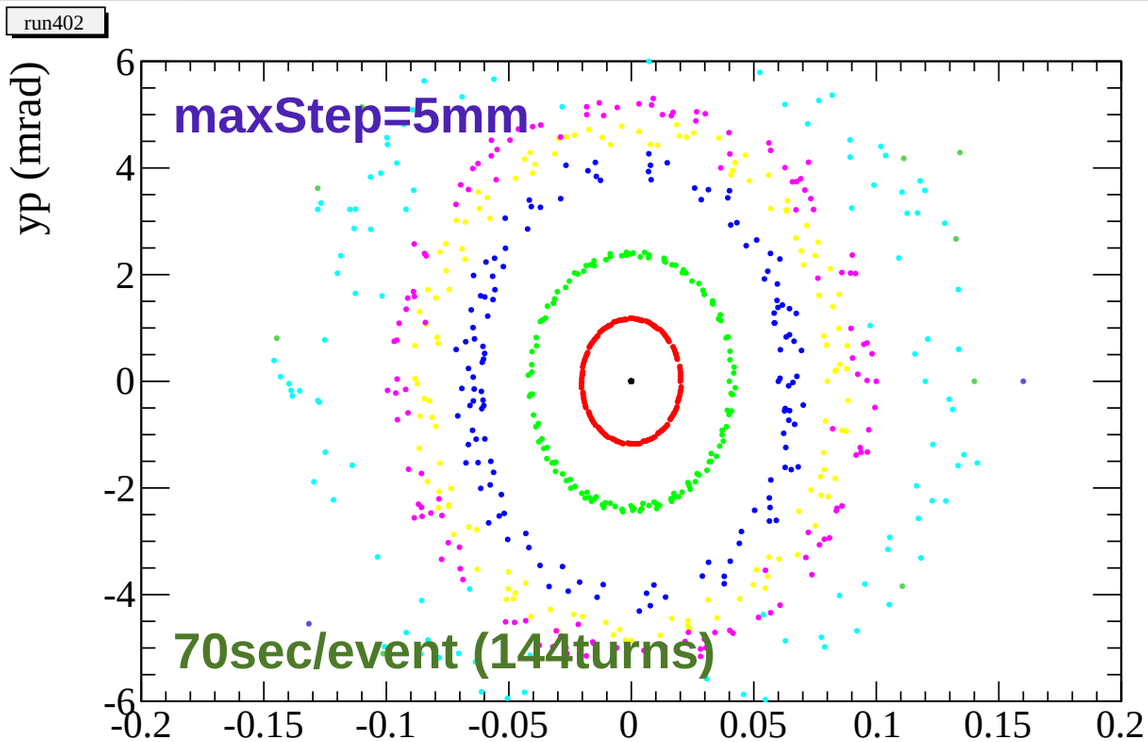


Use this

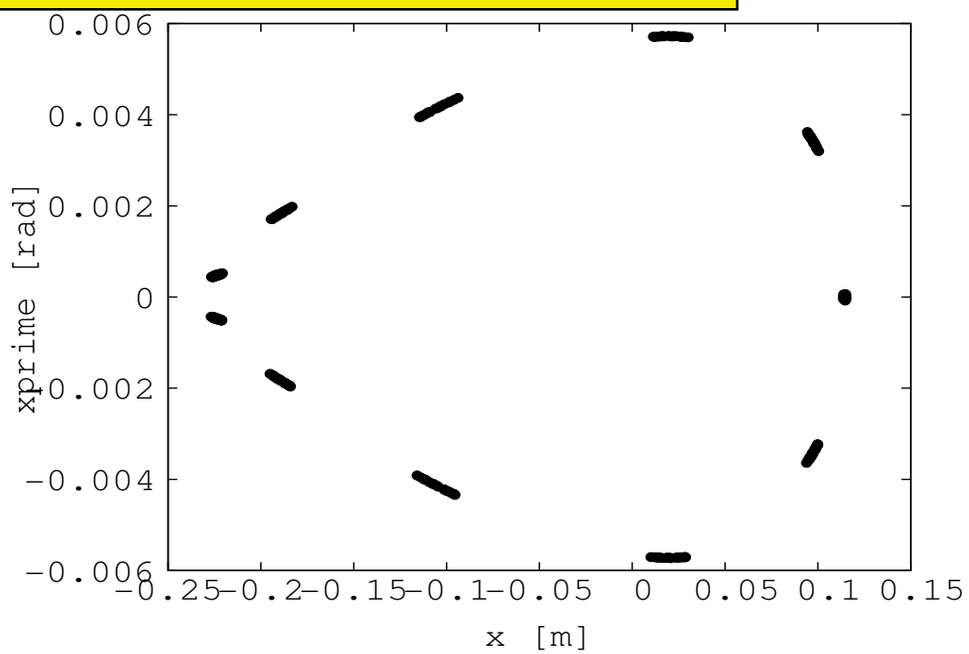
Comparison with JB's tracking results

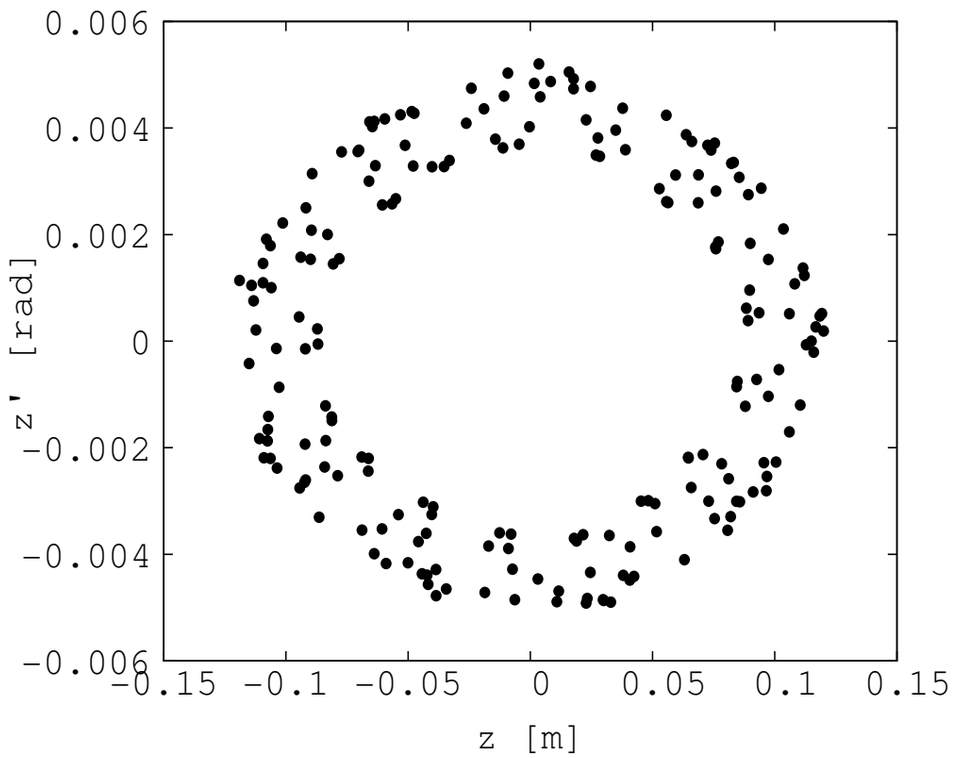
g4beamline



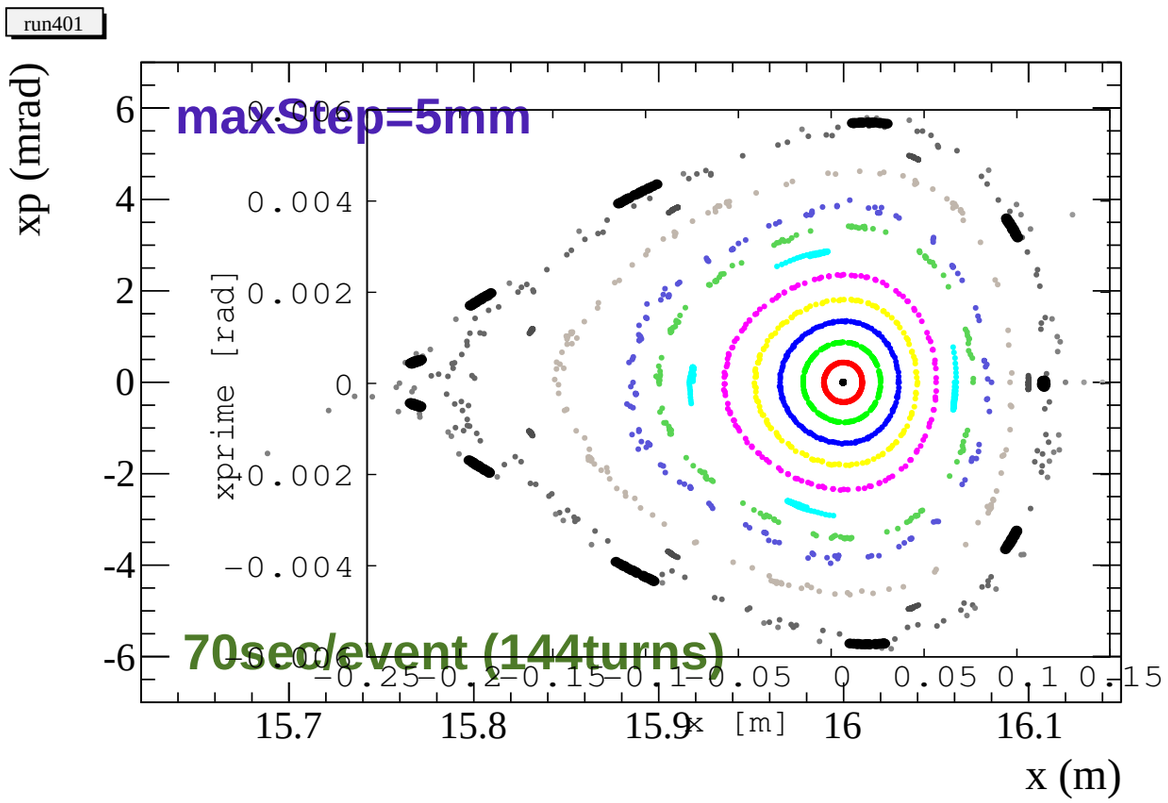


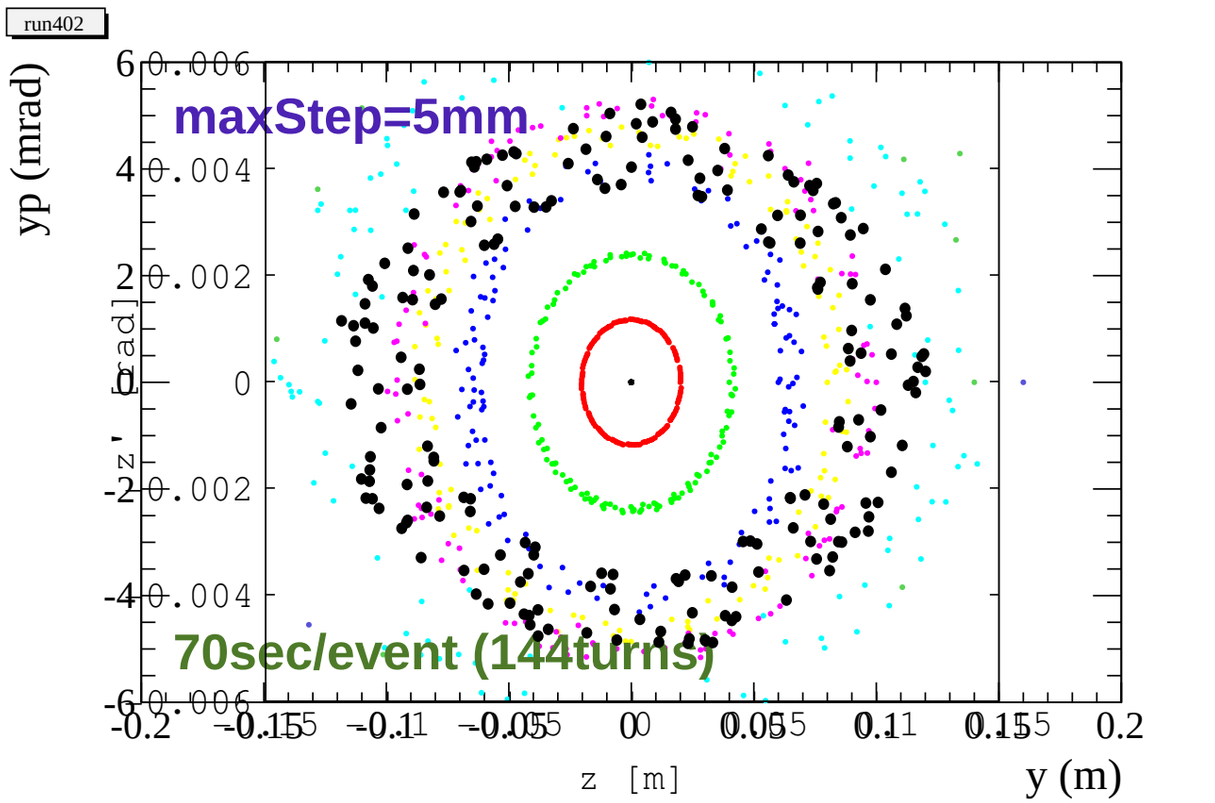
JB's original tracking code





Comparison b/w JB's results

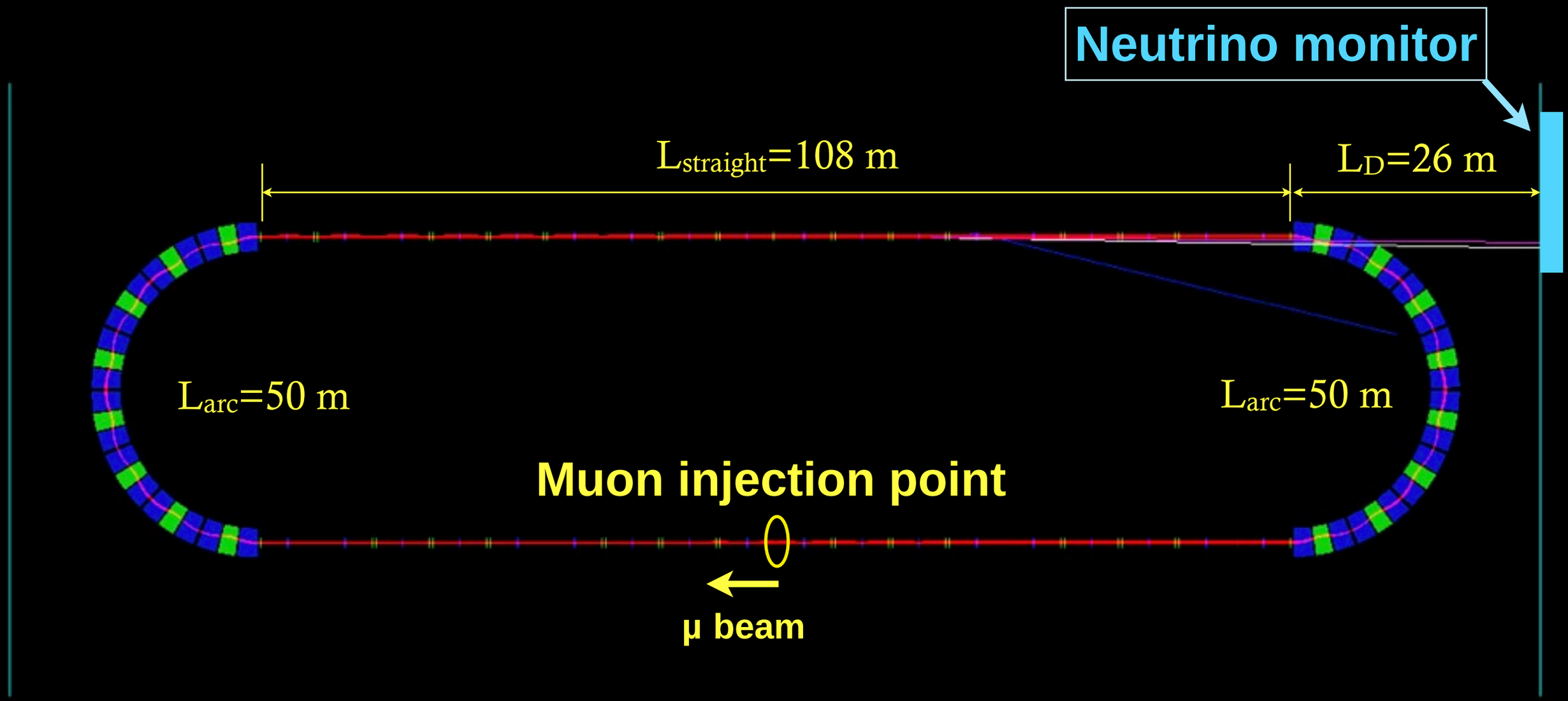




- The tracking results of g4beamline show very good agreement with the JB's result.
- I use maxstep=5mm in the following tracking.
  - note: The grid size of magnetic field maps must be also enough small to get reasonable accuracy.

Then, I turned the muon decay switch on to product neutrinos.

Neutrino production with JB's 2GeV Ring by g4beamline

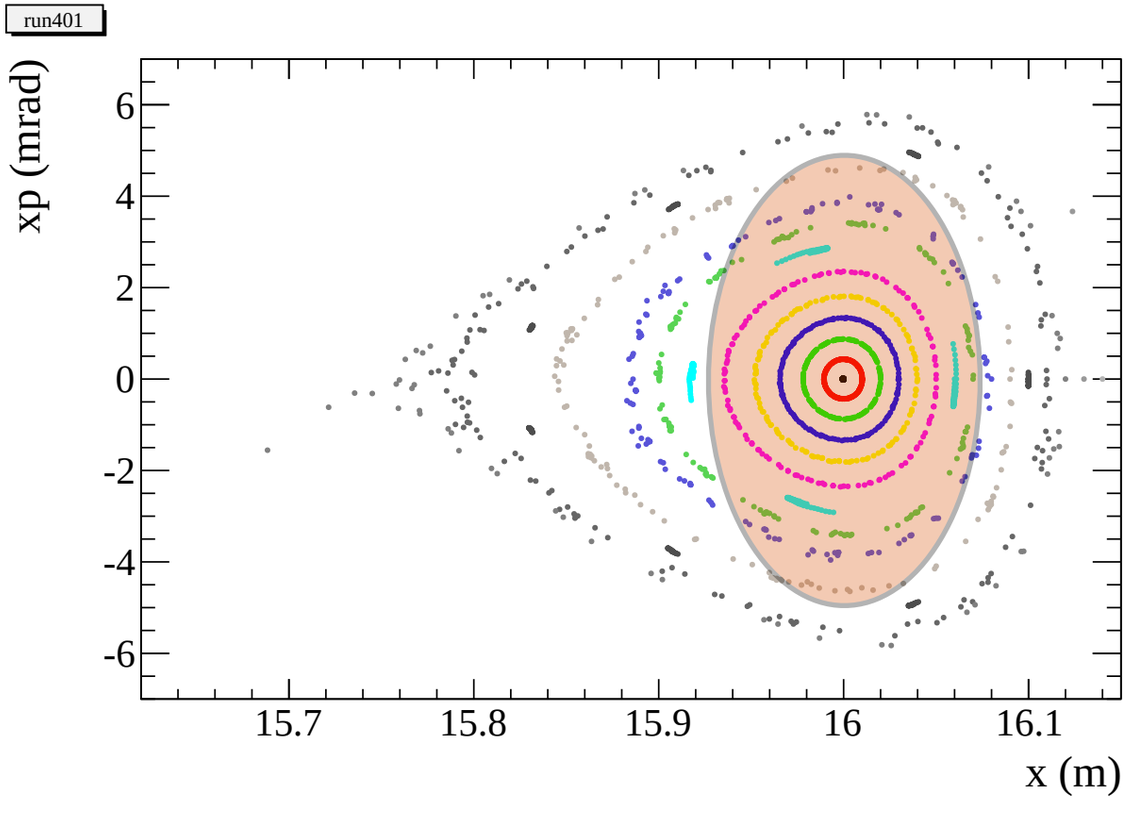


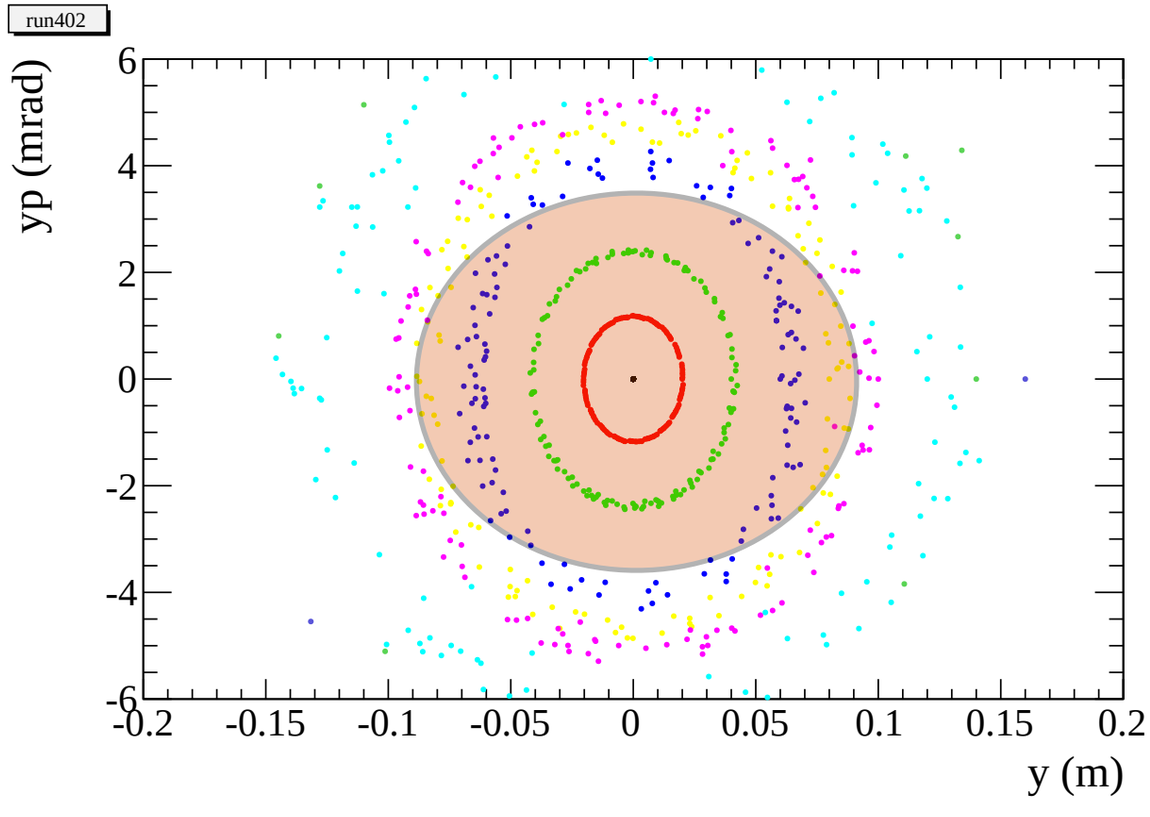
red: μ^- blue:e^- white:ν_e magenta:anti-ν_μ

Initial beam emittance of the muon

- Ellipse beam which is randomly generated on (X,Xp), (Y,Yp) with uniform density. (by g4bl command: *beam ellipse*). I tried two cases:
  - **E = 2.0 GeV**
    - ΔX : 0.075 m, ΔXp : 0.0050 rad
    - ΔY : 0.090 m, ΔYp : 0.0035 rad
    - ΔE : 0 GeV, Δt : 0ns
  - **E = 2.0 GeV ± 16%**
    - ΔX : 0.125 m, ΔXp : 0.0050 rad
    - ΔY : 0.090 m, ΔYp : 0.0035 rad
    - ΔE : 0.32 GeV, Δt : 0ns

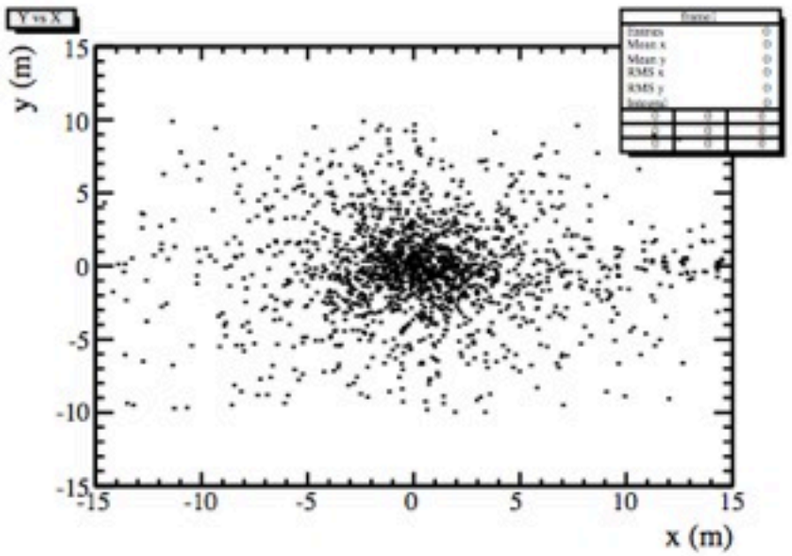
Beam size for E_μ=2GeV±16% is decided from the dispersion, but no dispersion matching was made in this simulation.

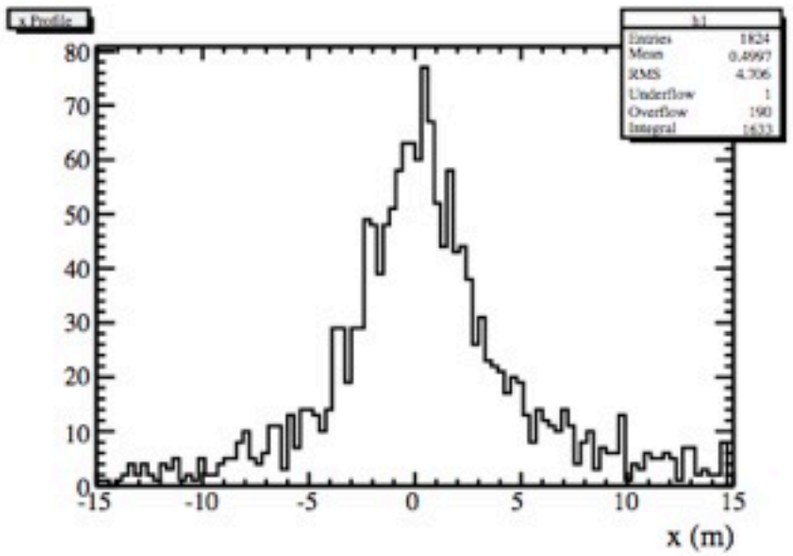


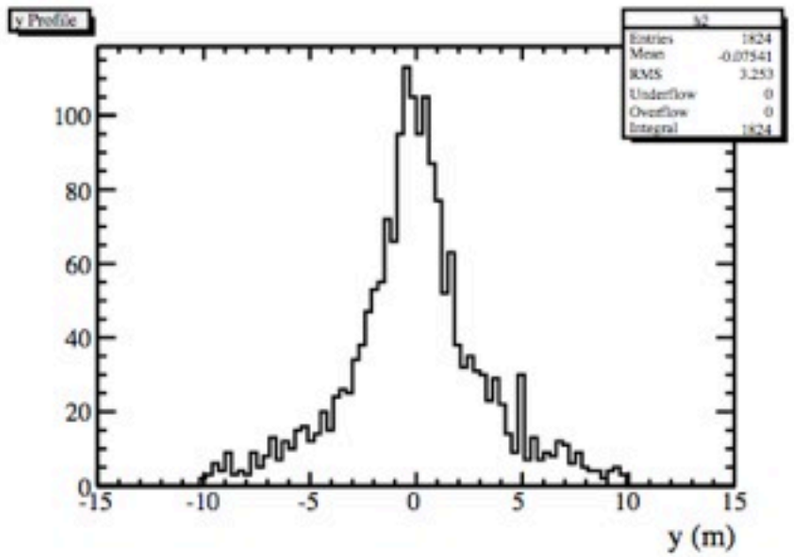


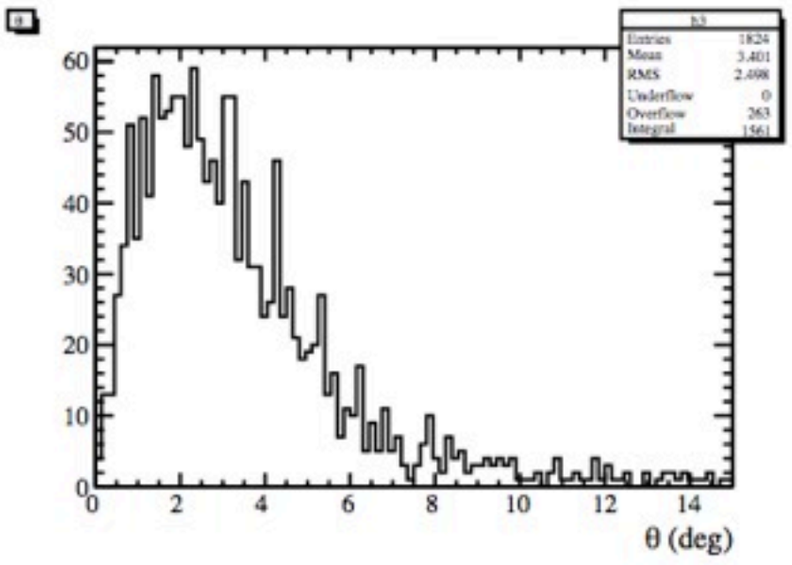
Neutrino beam at the monitor : E_μ=2.0GeV ± 0%

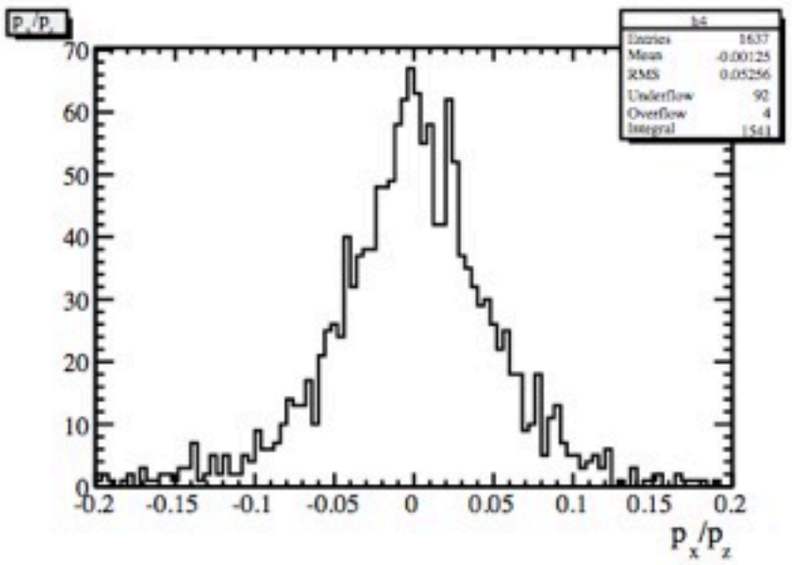
L_S=108 m, L_D=26 m

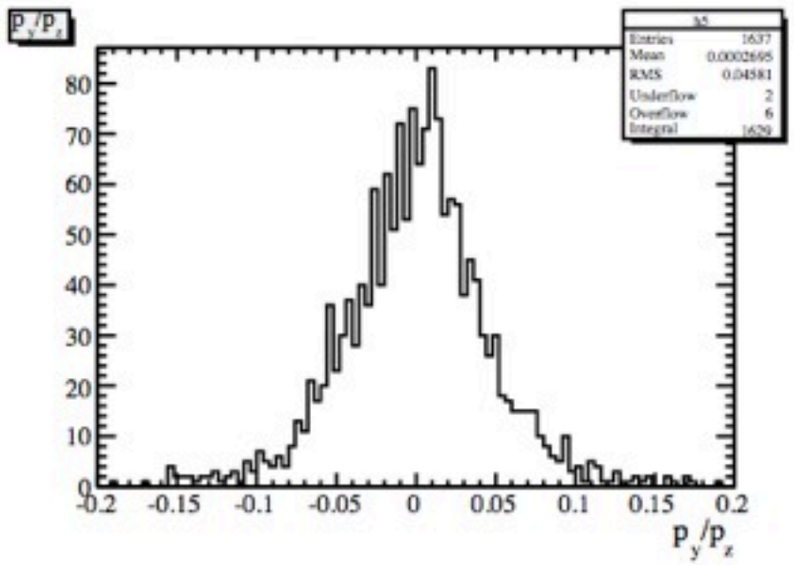












13 sec/event on icore7

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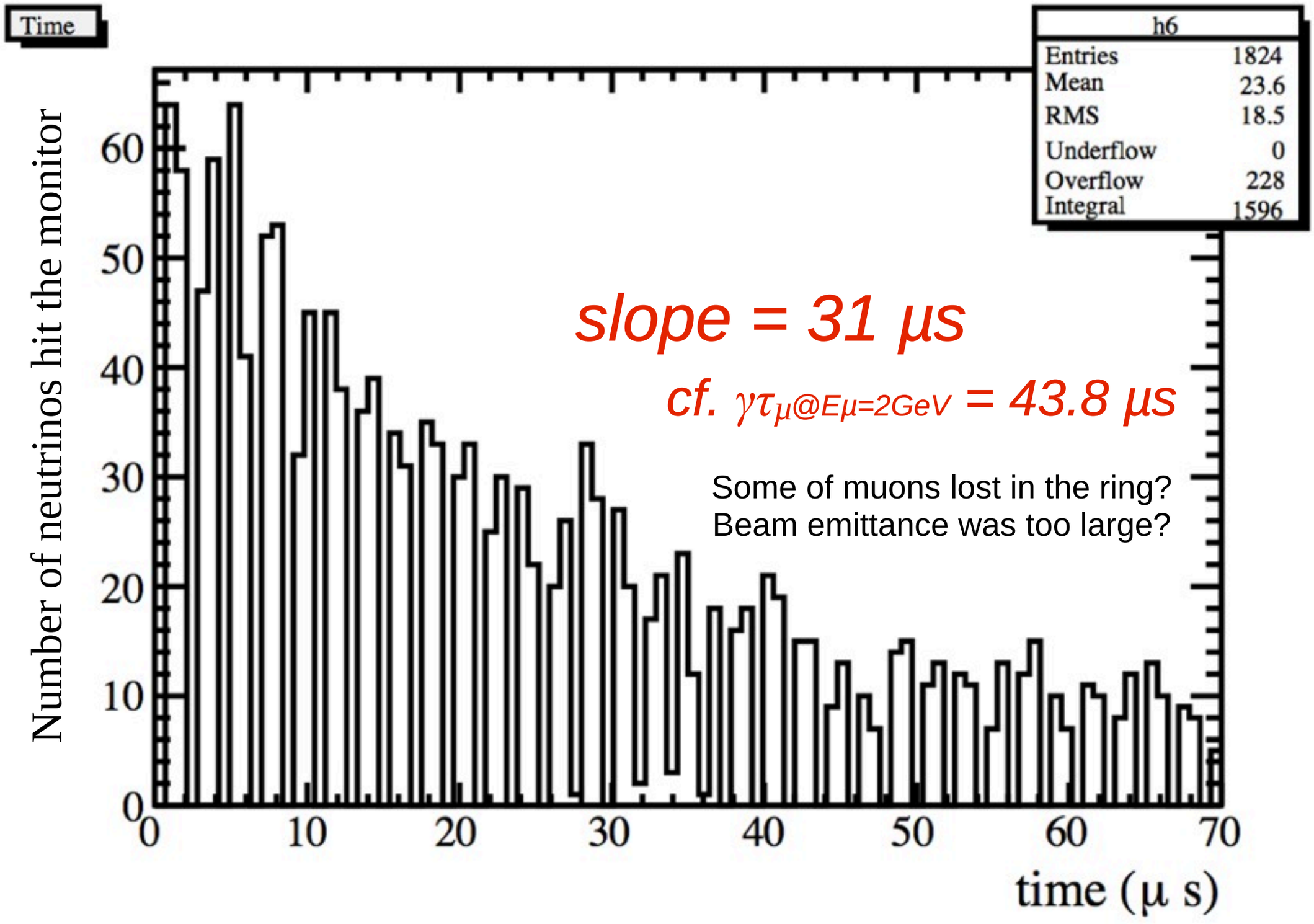

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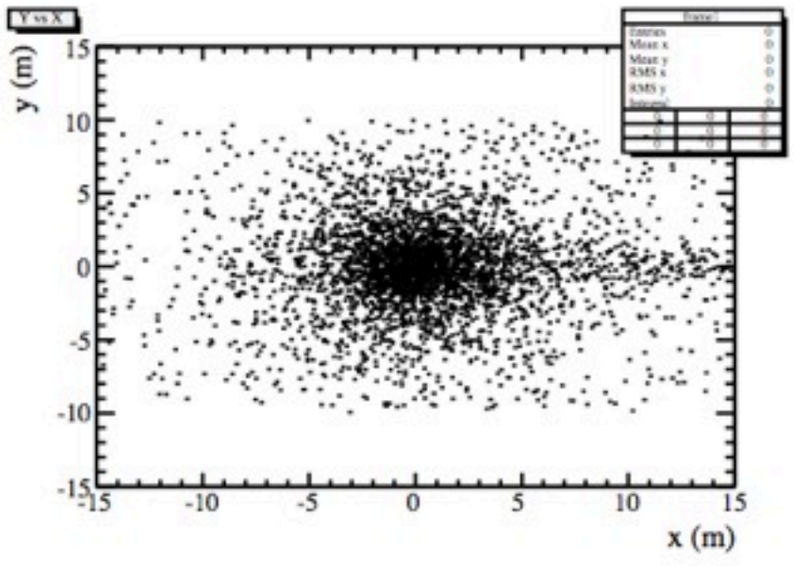

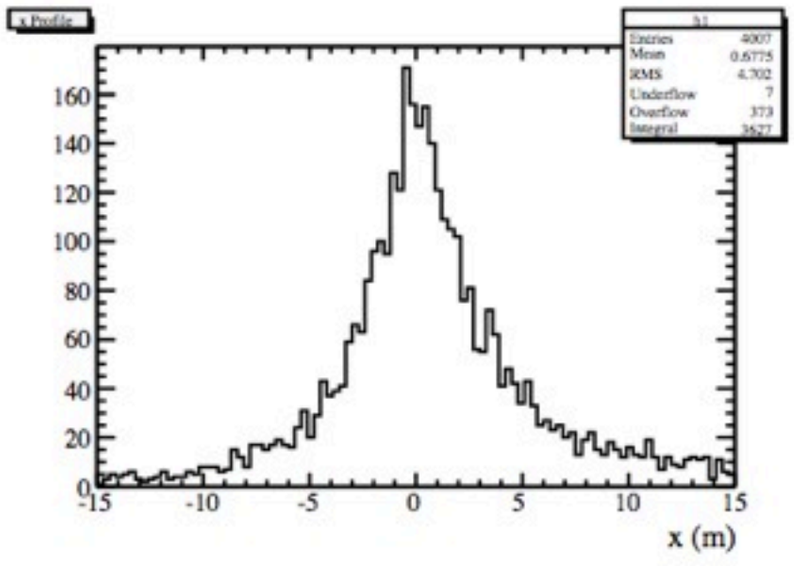

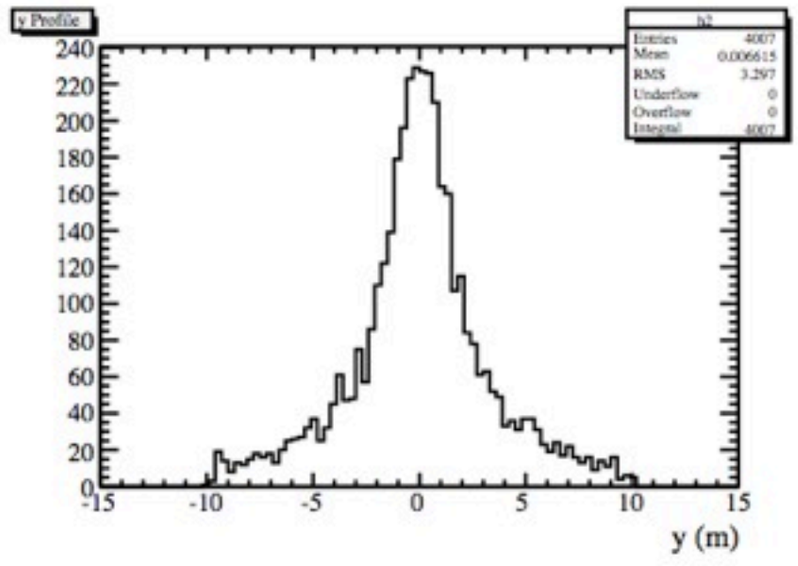

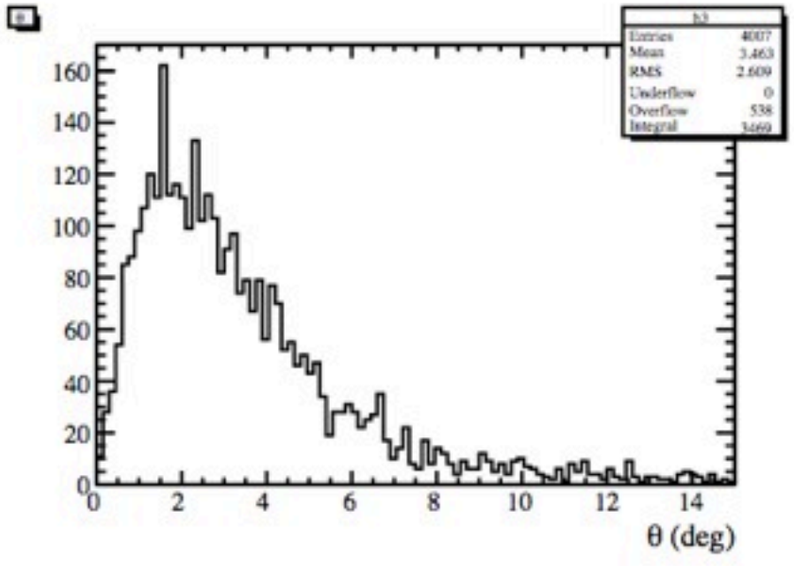

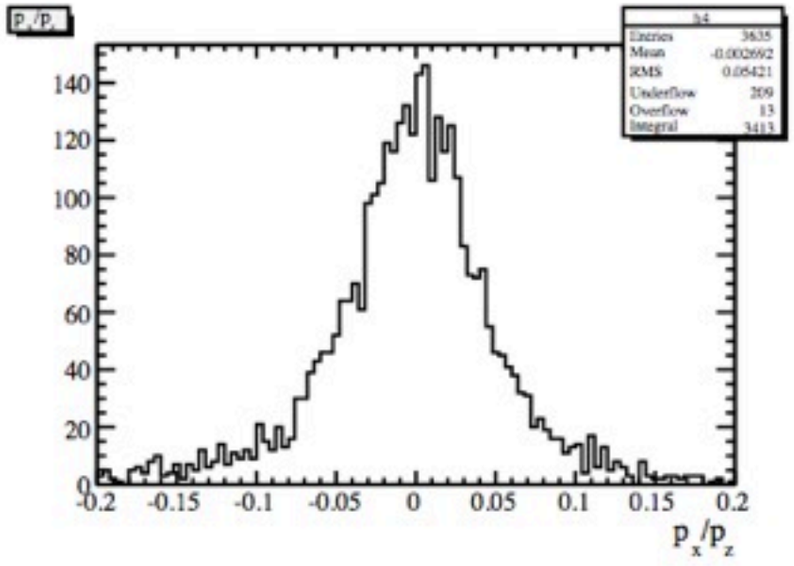

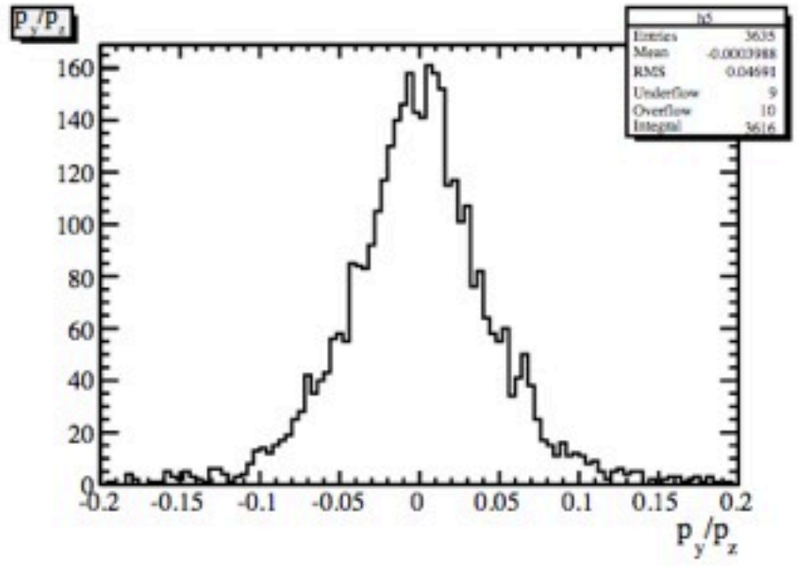

Muon decay Racetrack-FFAG ring for vSTORM (p_μ=3.8GeV/c, $\Delta p/p_0$=±20%)

designed by JB. Lagrange and Y. Mori (KURRI)

from JB.Lagrange and Y.Mori, acc-kurri-0731-03-2012

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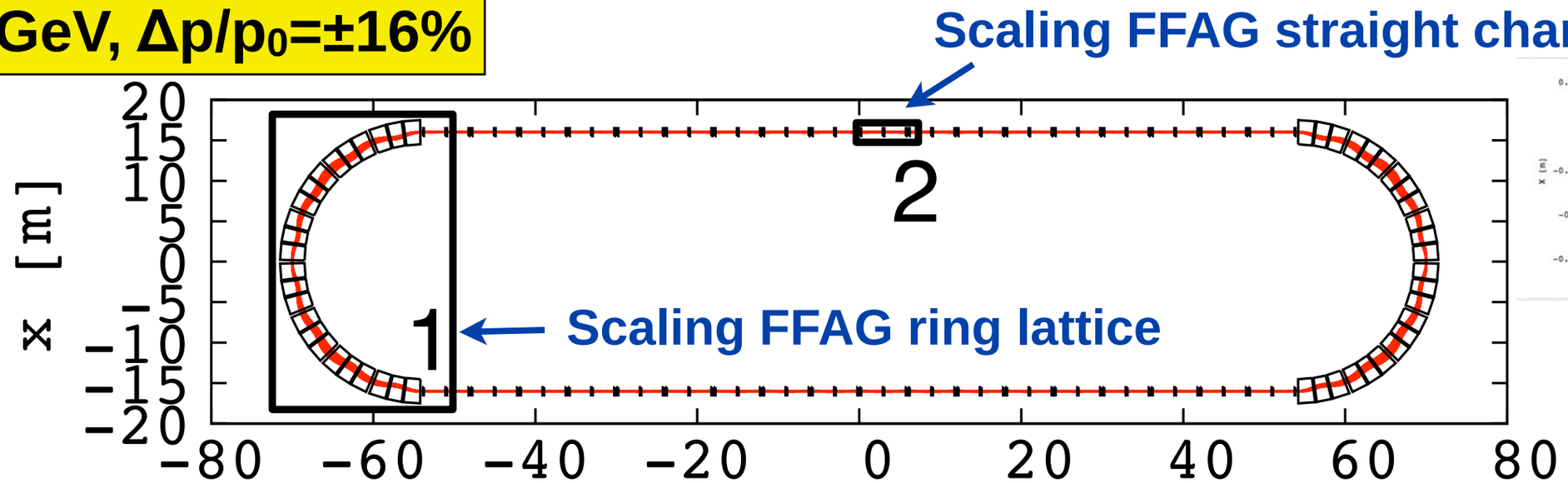
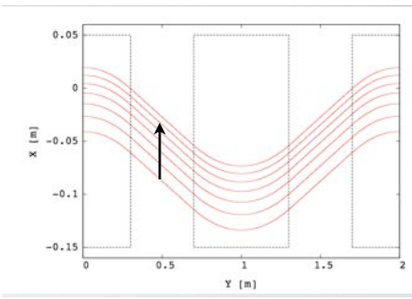
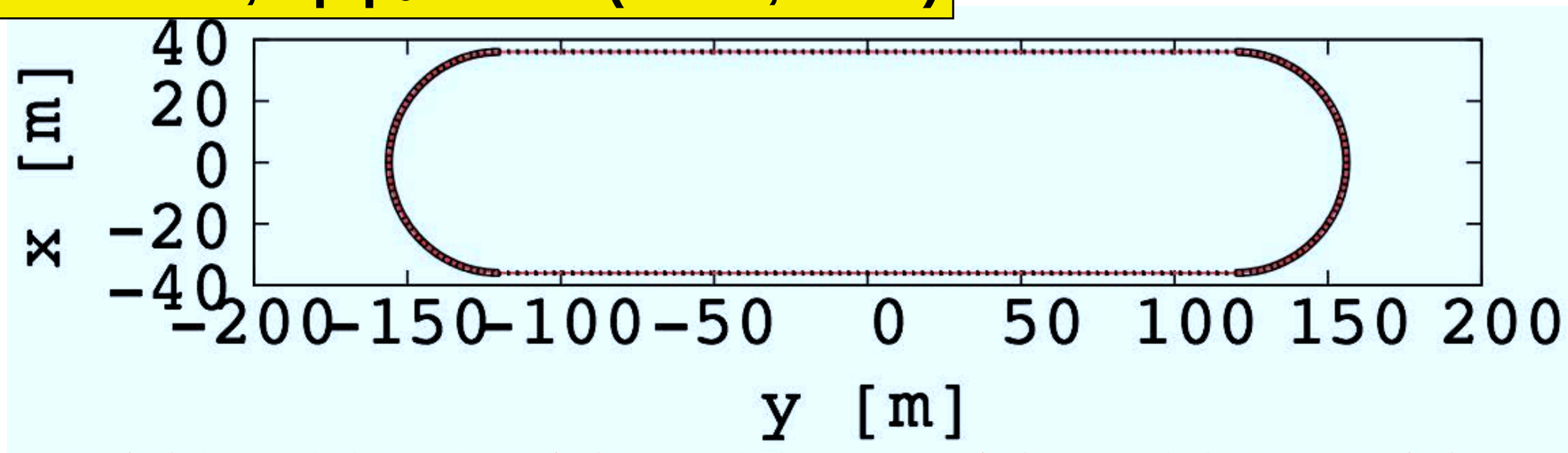


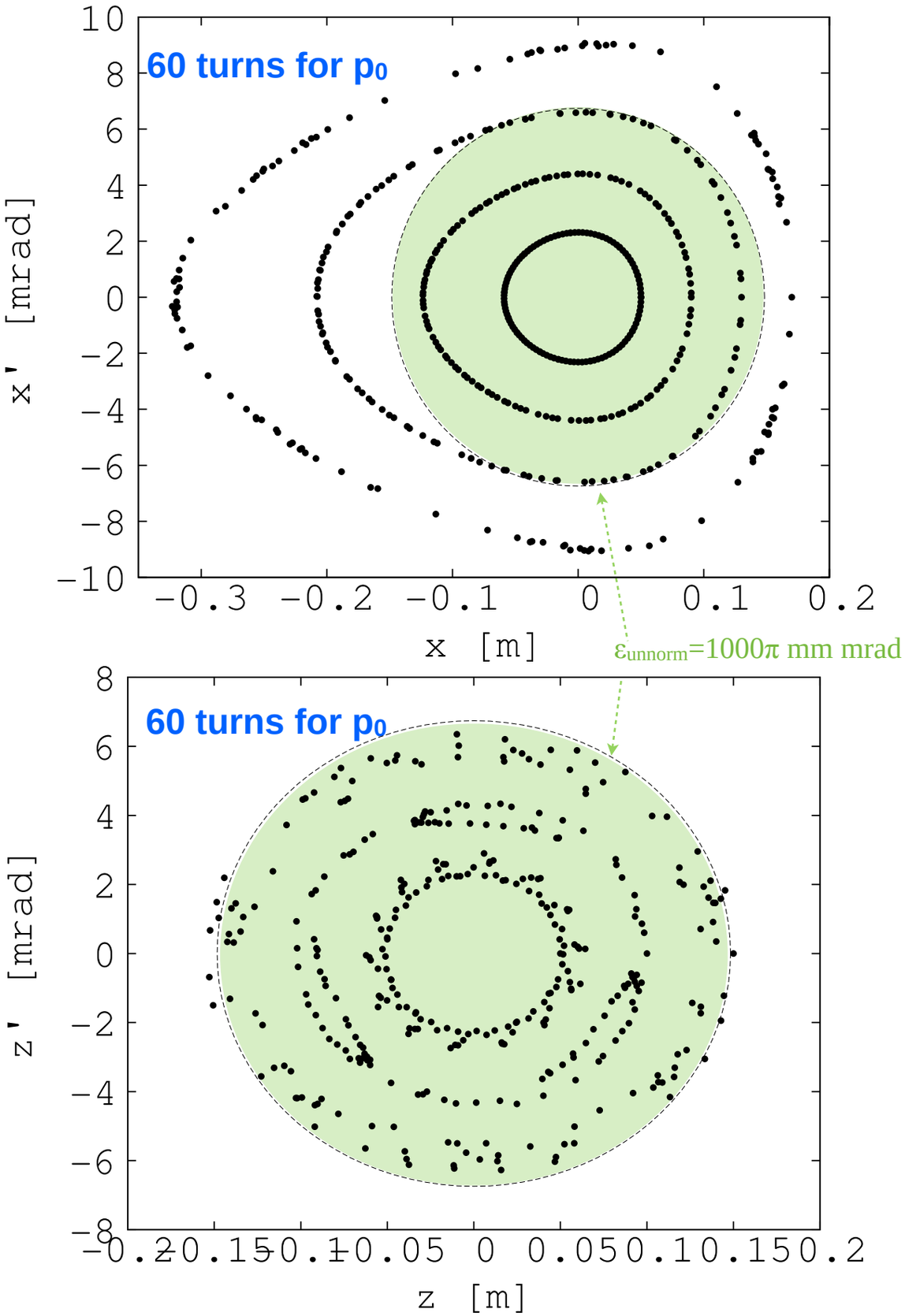


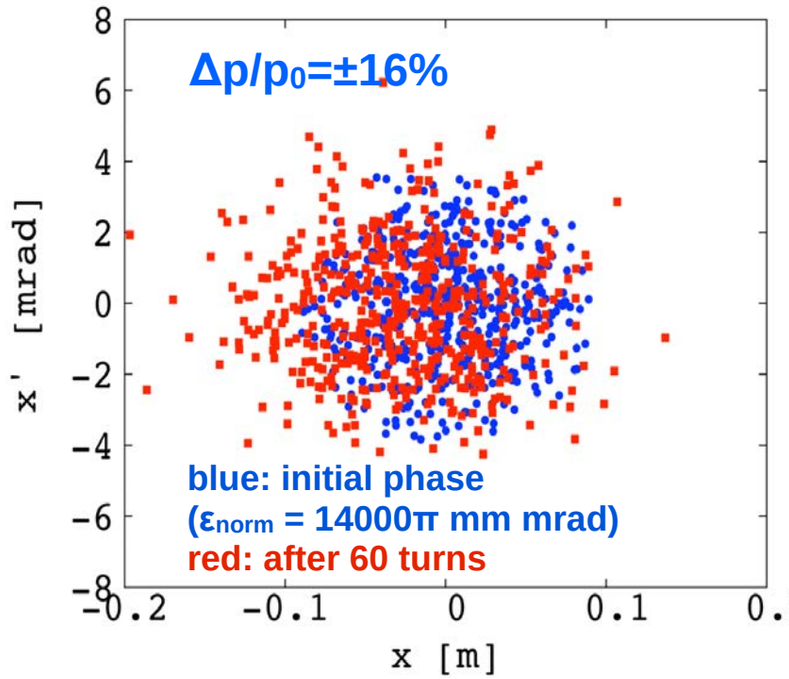
p_μ=3.8GeV/c, $\Delta p/p_0$=±16% (±20%,±26%)

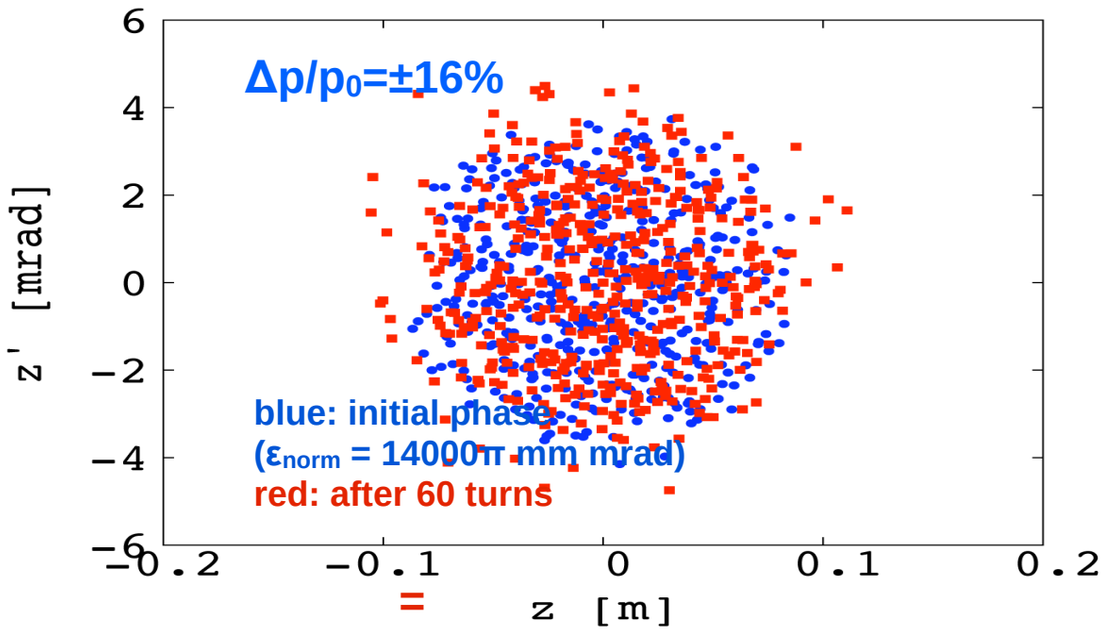


- They studied performance of these FFAGs by their original tracking code, which cannot study decay of muon.

JB's Lattice for p_μ=3.8GeV/c: Acceptance







from JB.Lagrange and Y.Mori, acc-kurri-0731-03-2012

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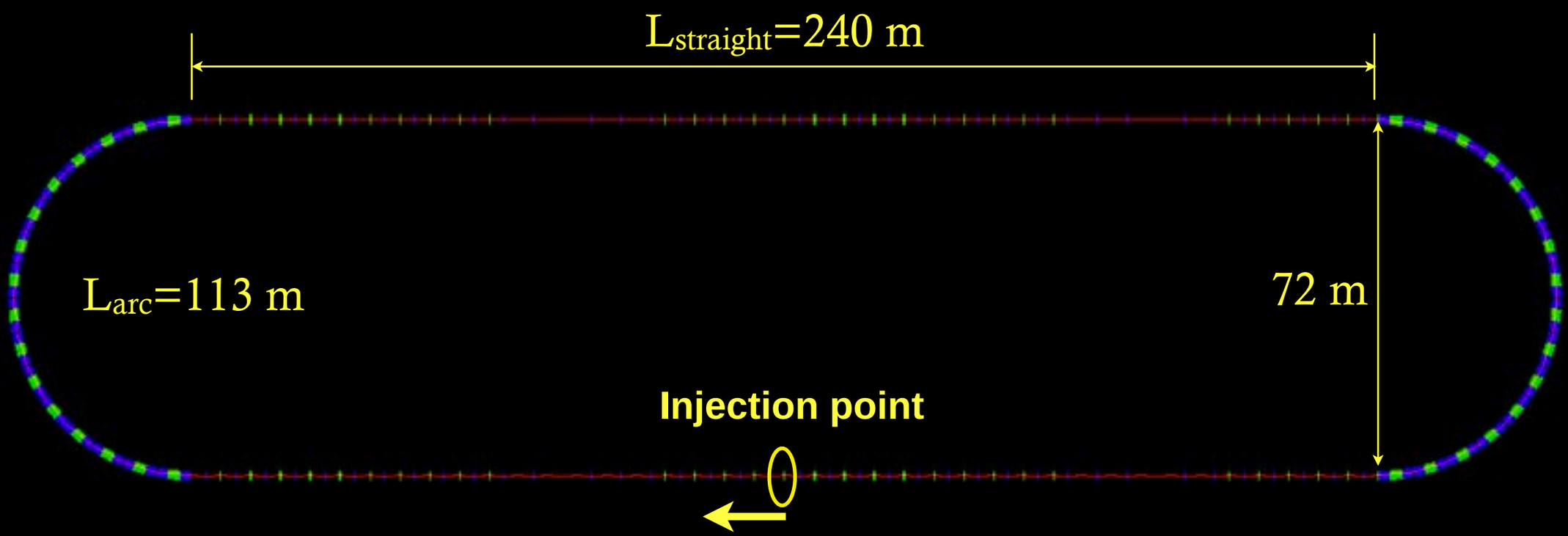
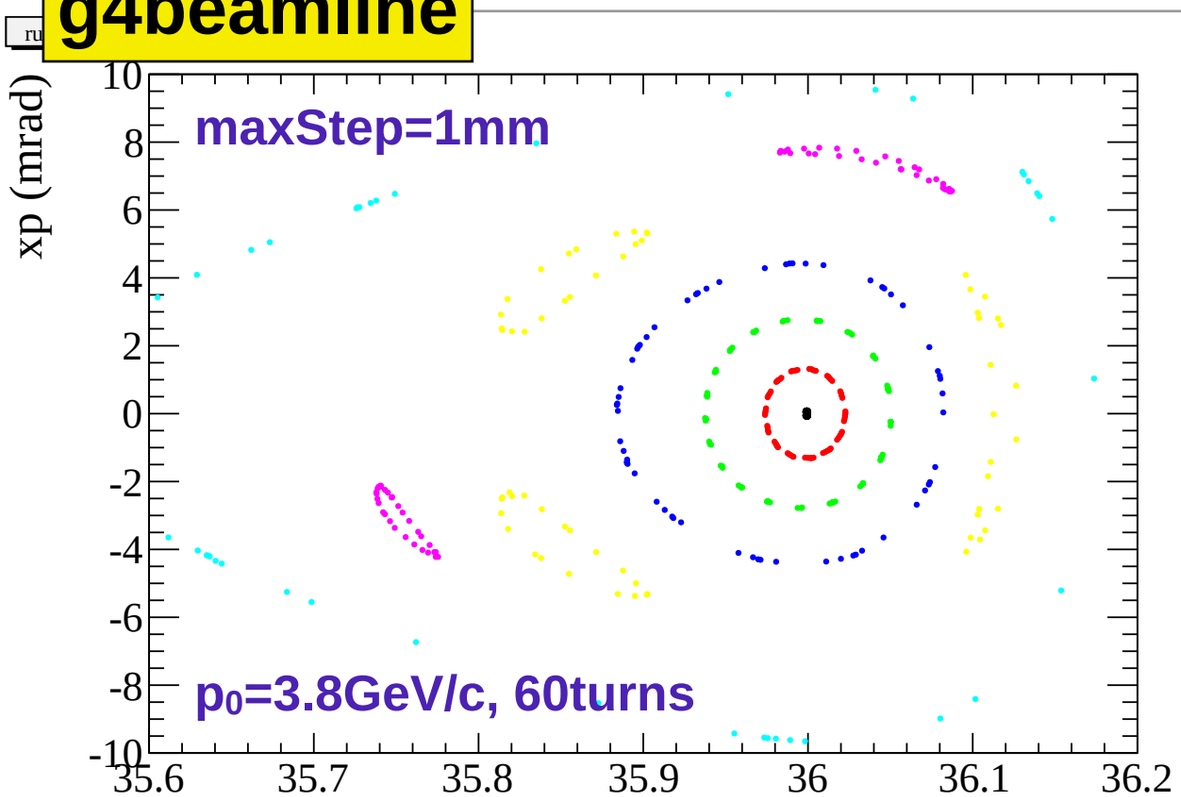
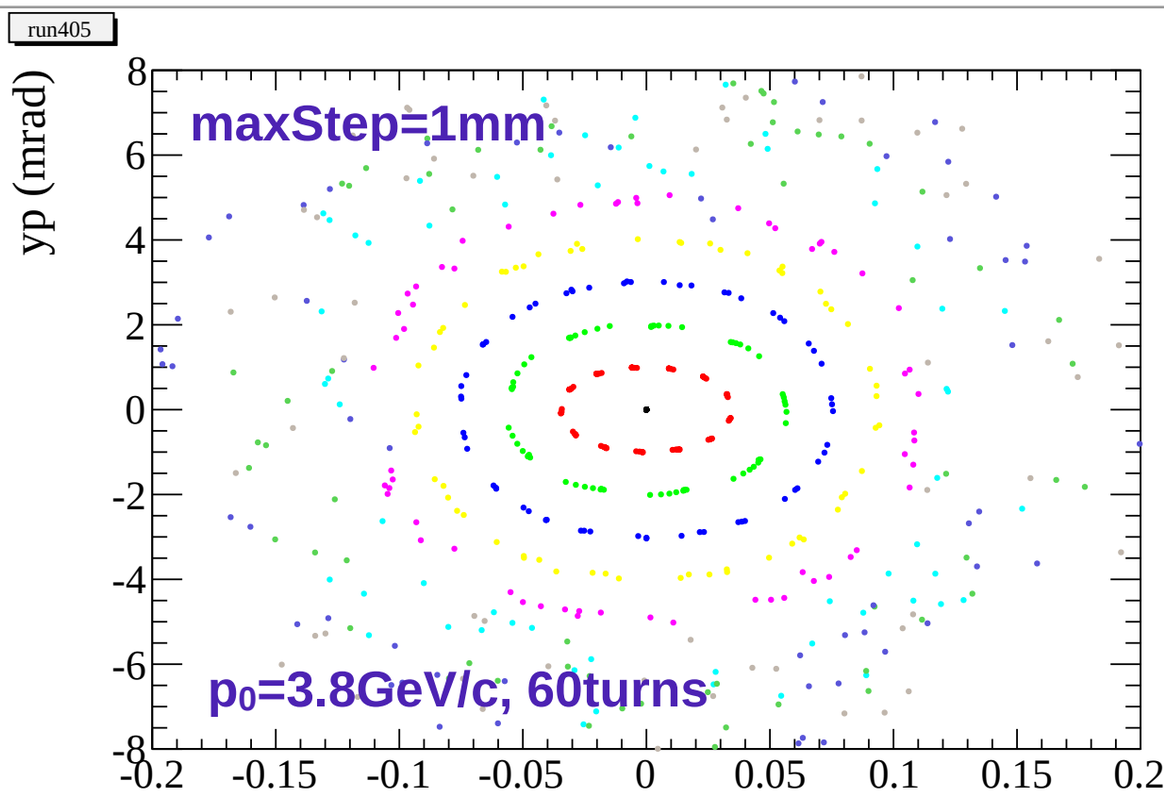


red: μ^- blue:e^- white:ν_e magenta:anti-ν_μ

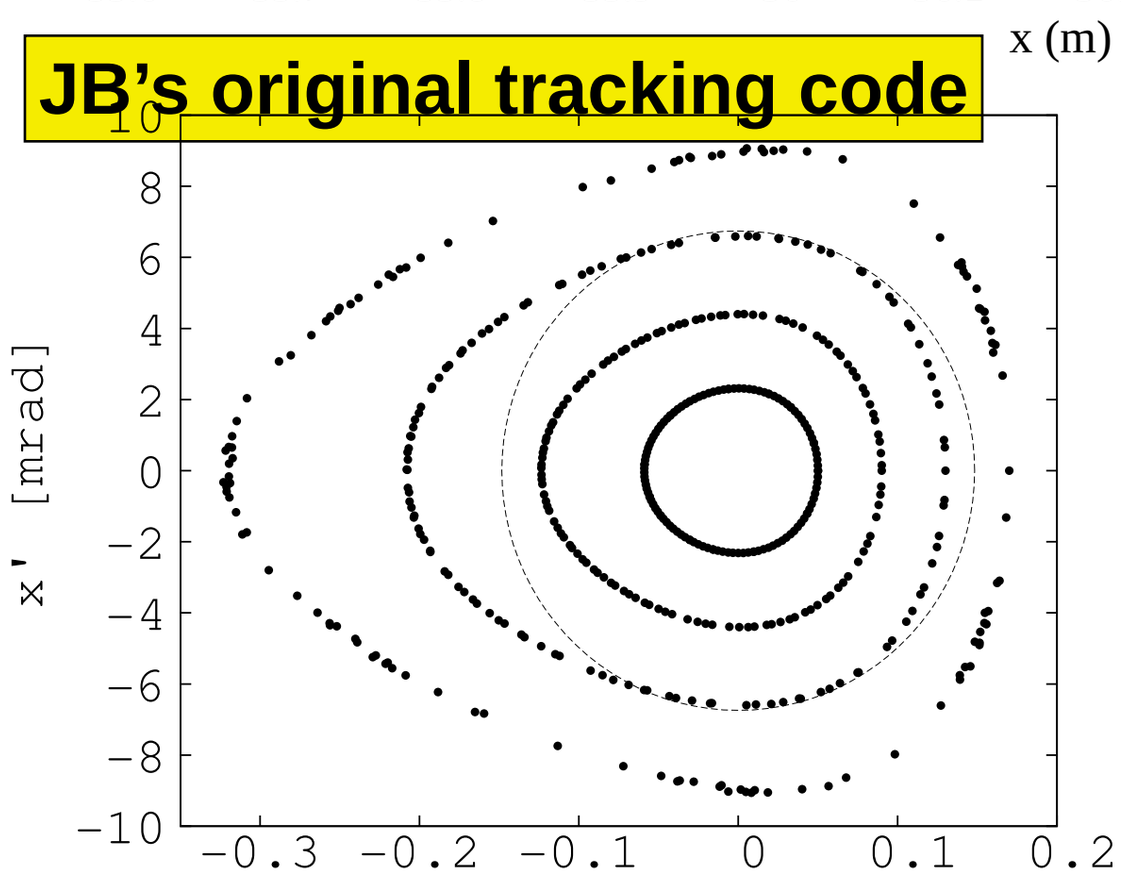
Comparison with JB's tracking results ($p=p_0=3.8$GeV/c)

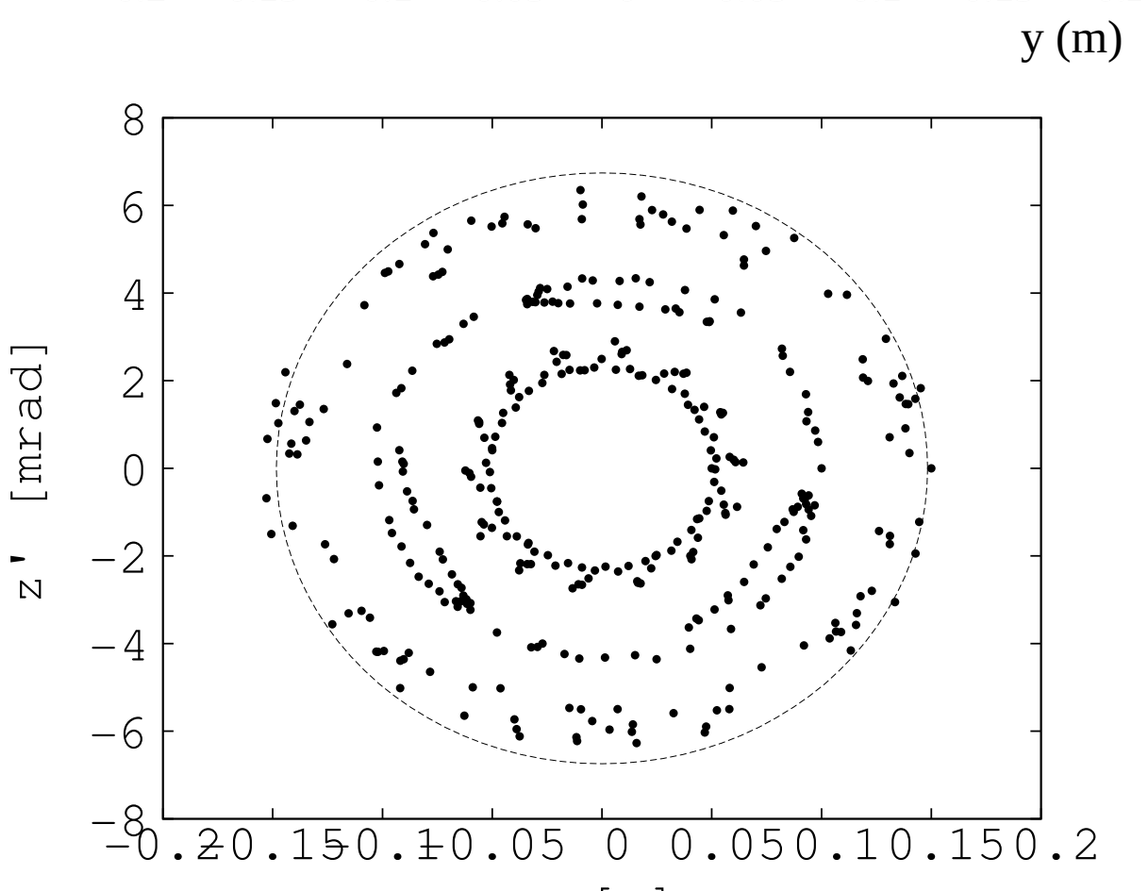
g4beamline



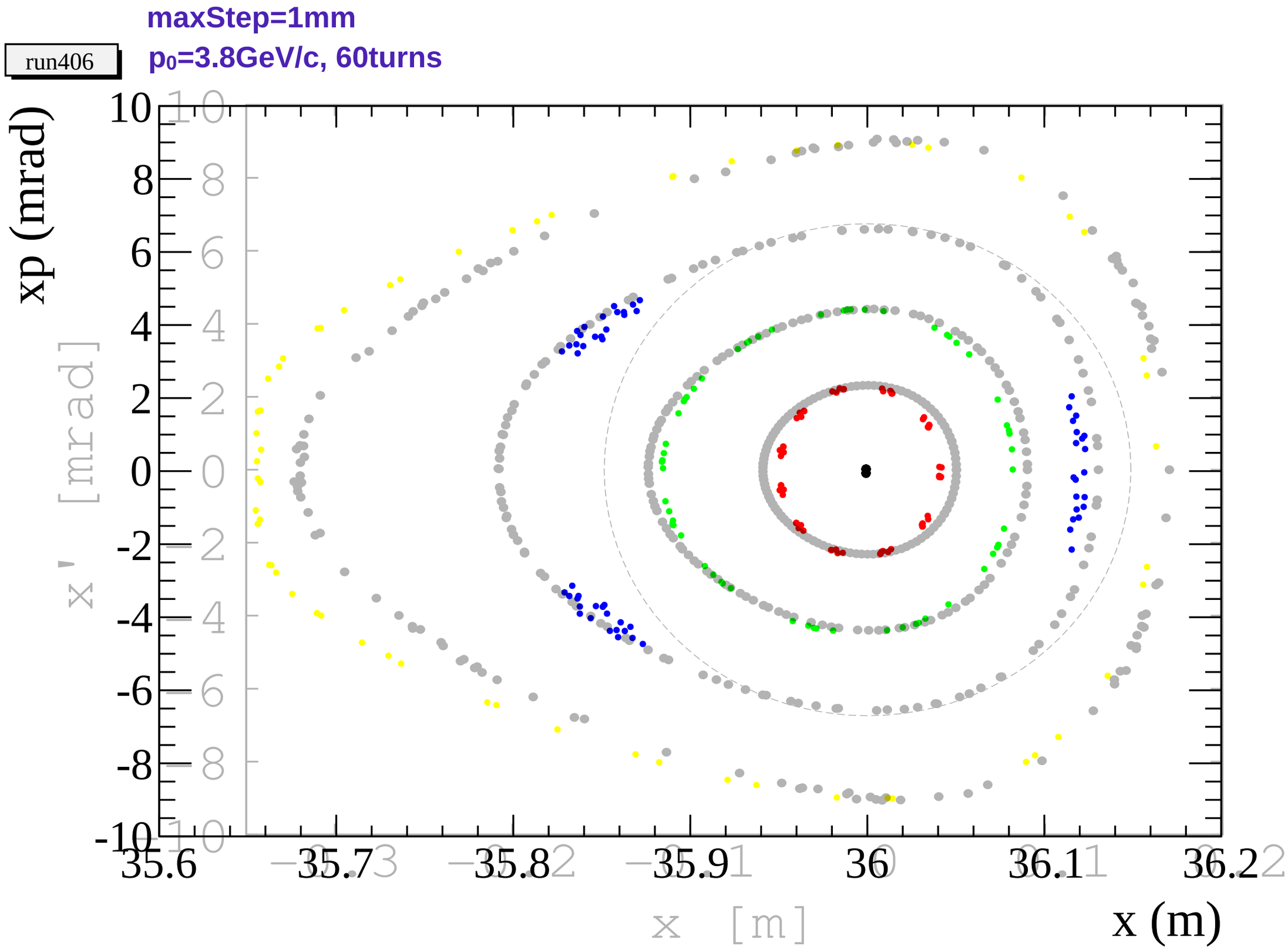


JB's original tracking code





Comparison with JB's tracking results ($p=p_0=3.8GeV/c$)



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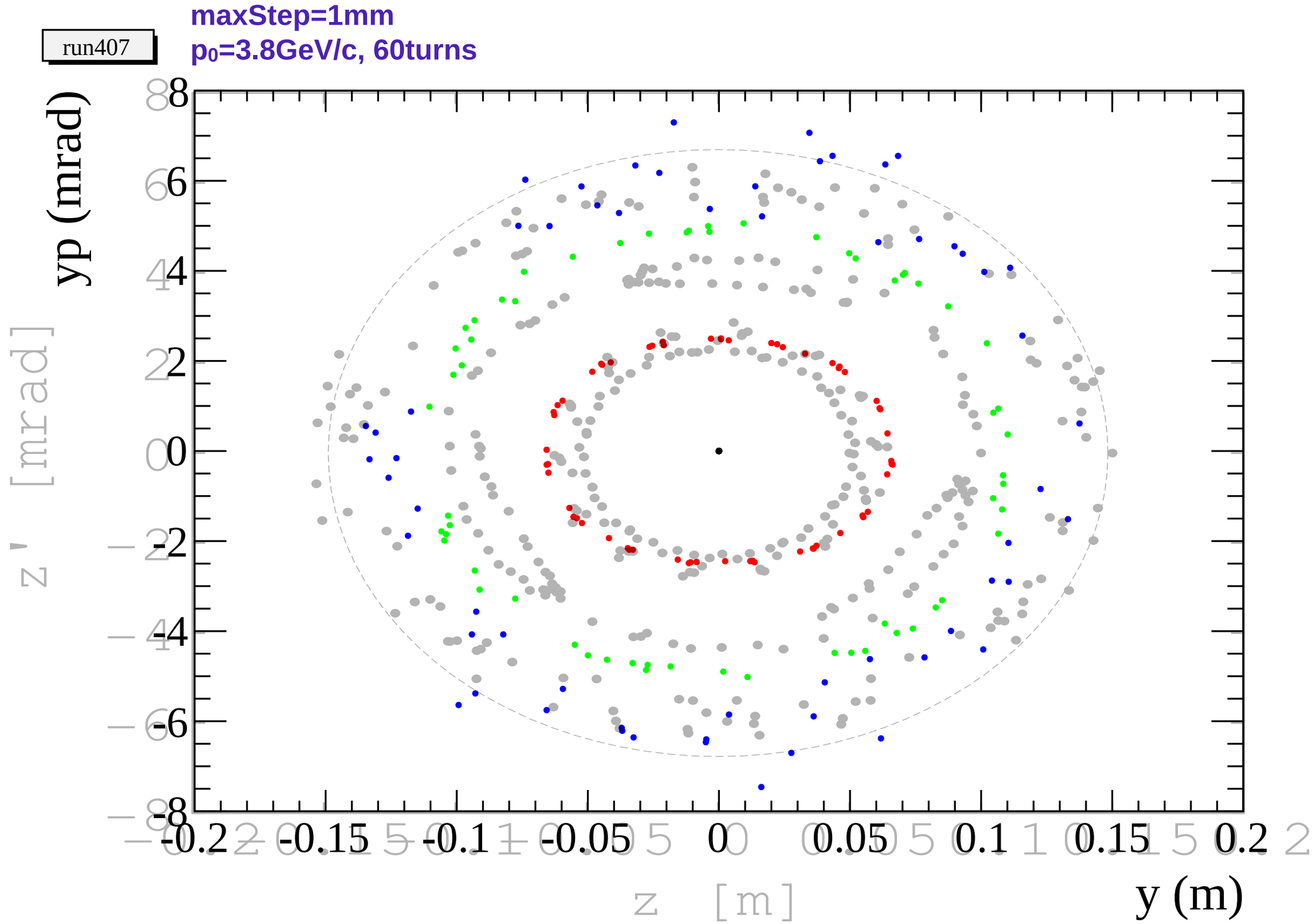


Study Plan for 3.8GeV.c RFFAG with g4baemline

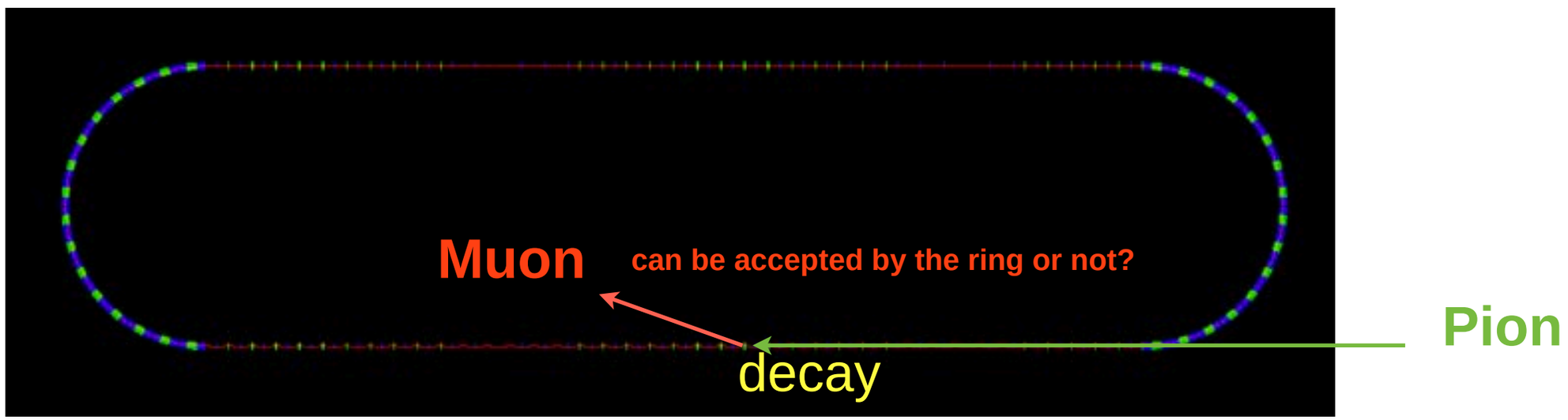
- Tracking for ±16%, ±20%, and ±26%
  - detail comparison with JB’s tracking result
- neutrino production
  - from muon decay in the ring
  - from pion injection
    - I need a realistic pion distribution at the injection point
    - MARS --> transport beam line --> injection

Decay ring acceptance for muon from pion decay

Muon yield estimation in the LoI

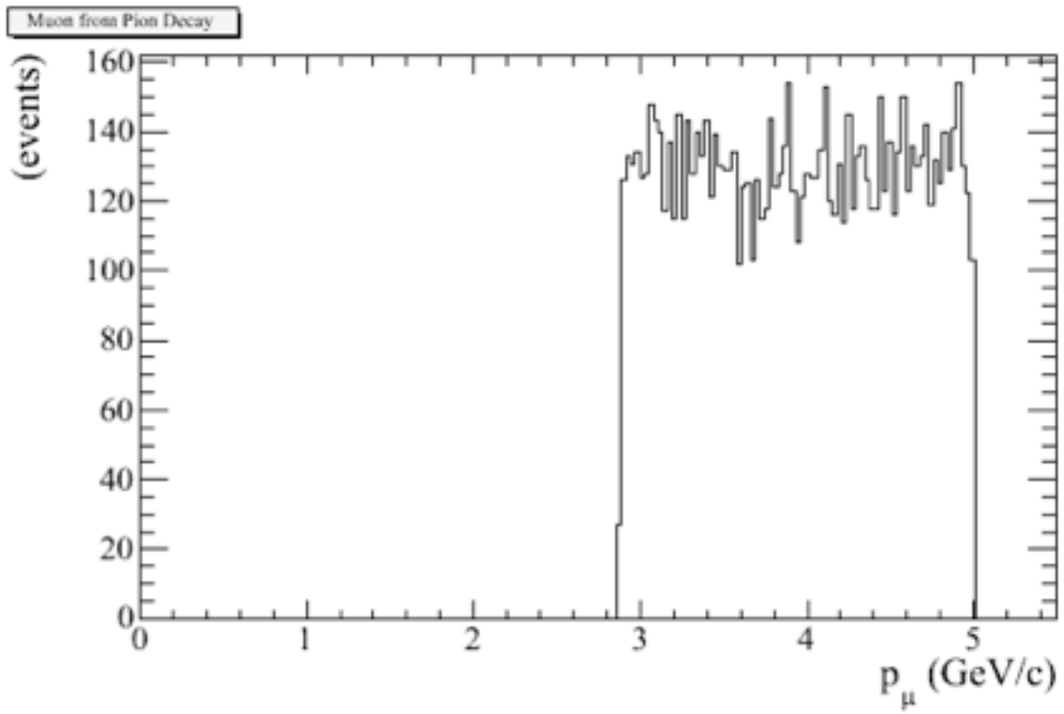
Table II. Relative μ yield for FODO vs. RFFAG rings

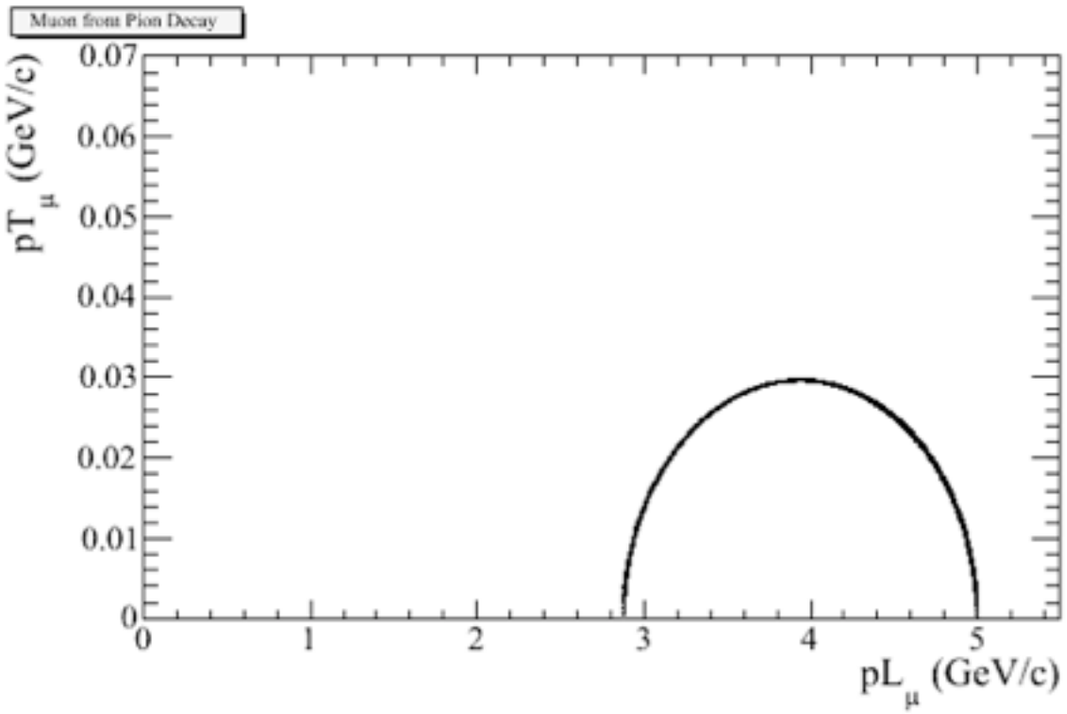
Parameter	FODO	RFFAG
$L_{straight}$ (m)	150	240
Circumference (m)	350	606
Dynamic aperture A_{dyn}	0.7	0.95
Momentum acceptance	$\pm$ 10%	$\pm$ 16%
π/POT within momentum acceptance	0.112	0.171
Fraction of π decaying in straight (F_s)	0.41	0.57
Ratio of $L_{straight}$ to ring circumference (Ω)	.43	.40
Relative factor ($A_{dyn} \times \pi/\mathrm{POT} \times F_s \times \Omega$)	0.014	0.037

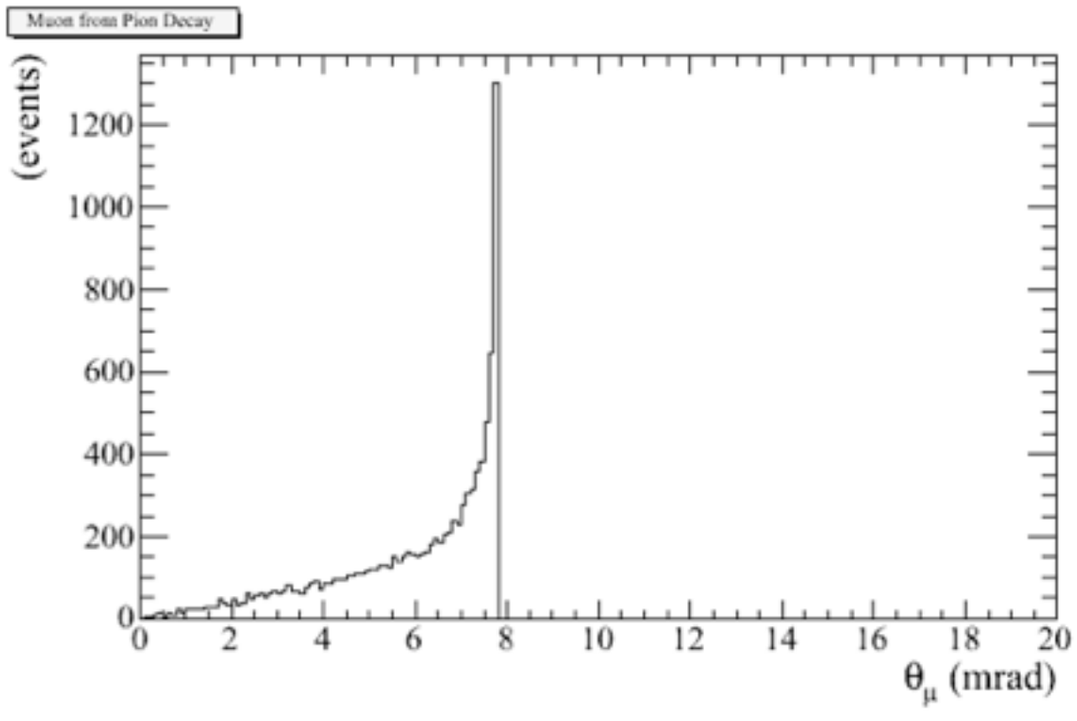


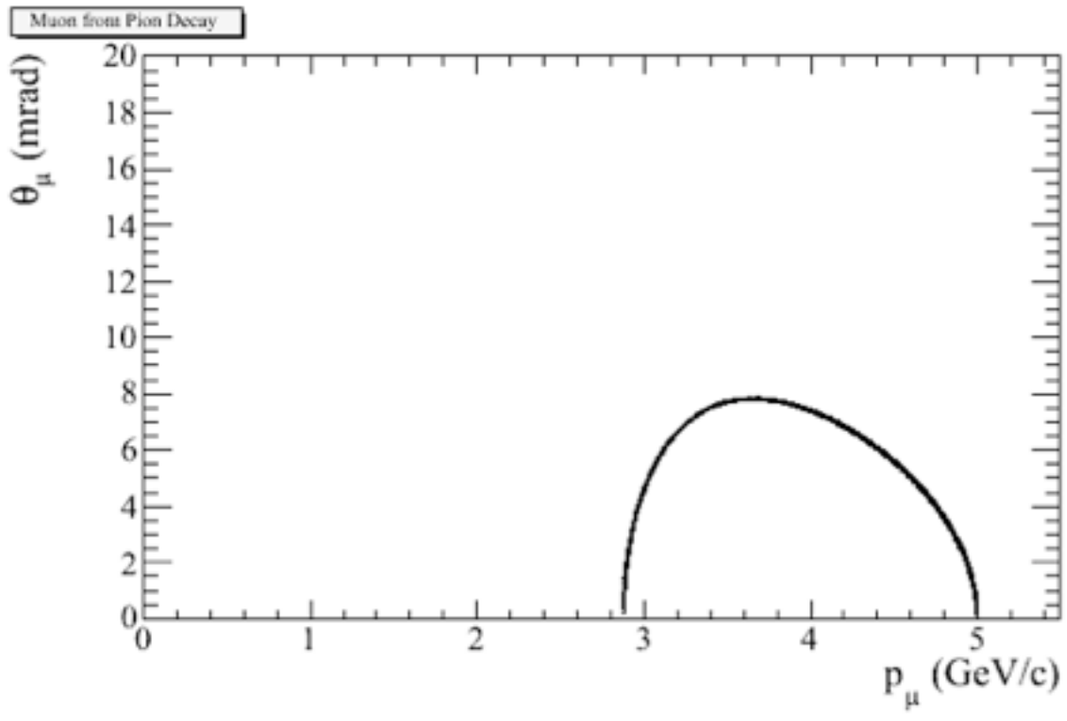
- The acceptance of muon from pion decay is missing.
- I made a rough estimation of the acceptance for the 3.8GeV/c RFFAG by kinamatical calculation with the Lorenz boost.

muon from 5GeV/c pion decay with ε_π=0

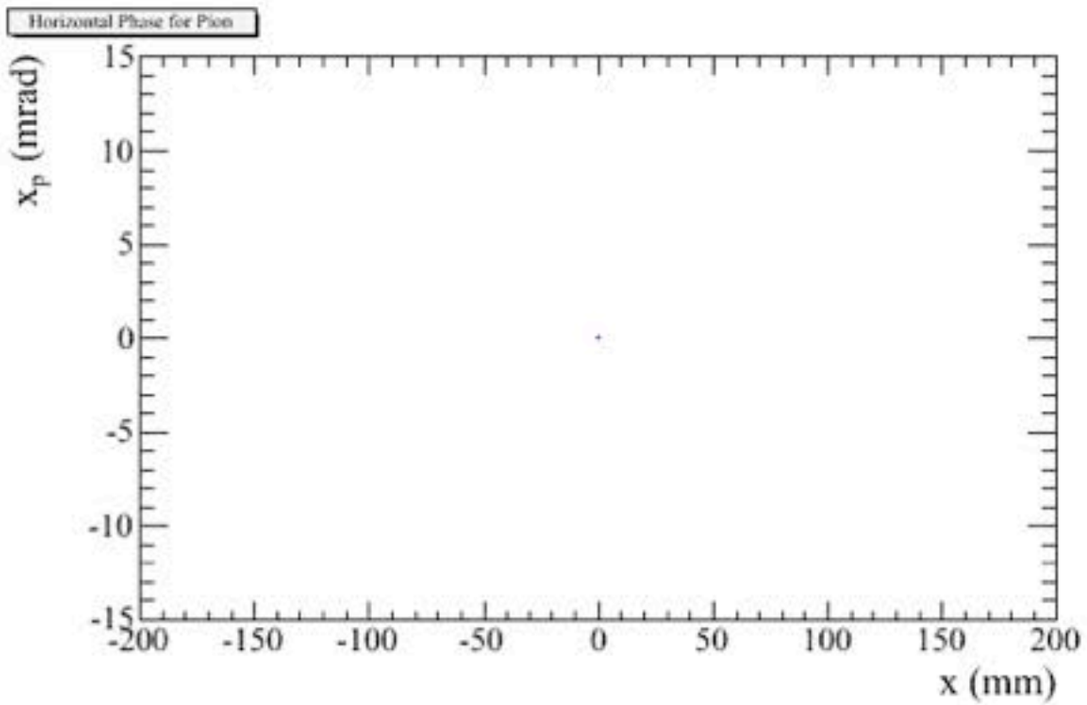


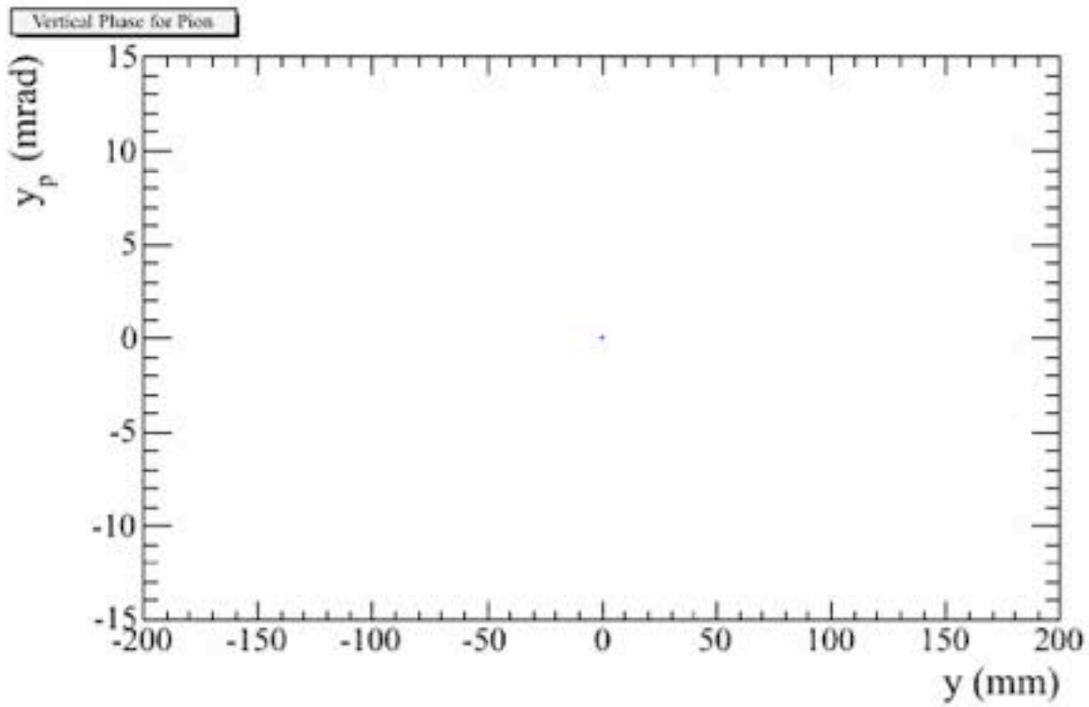


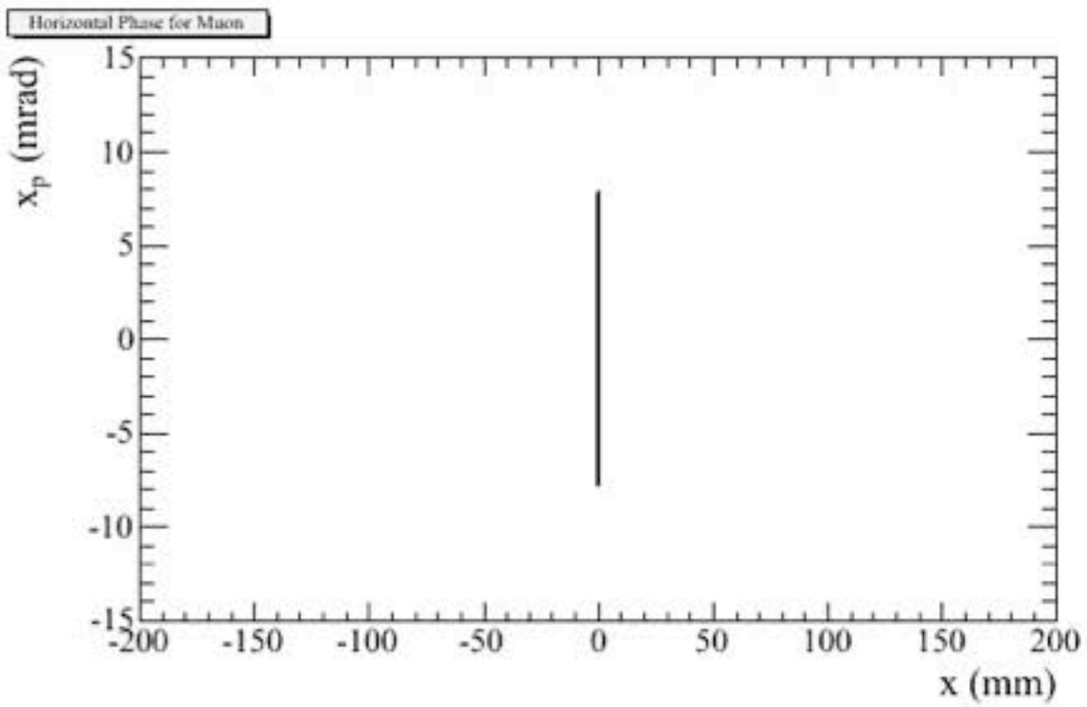


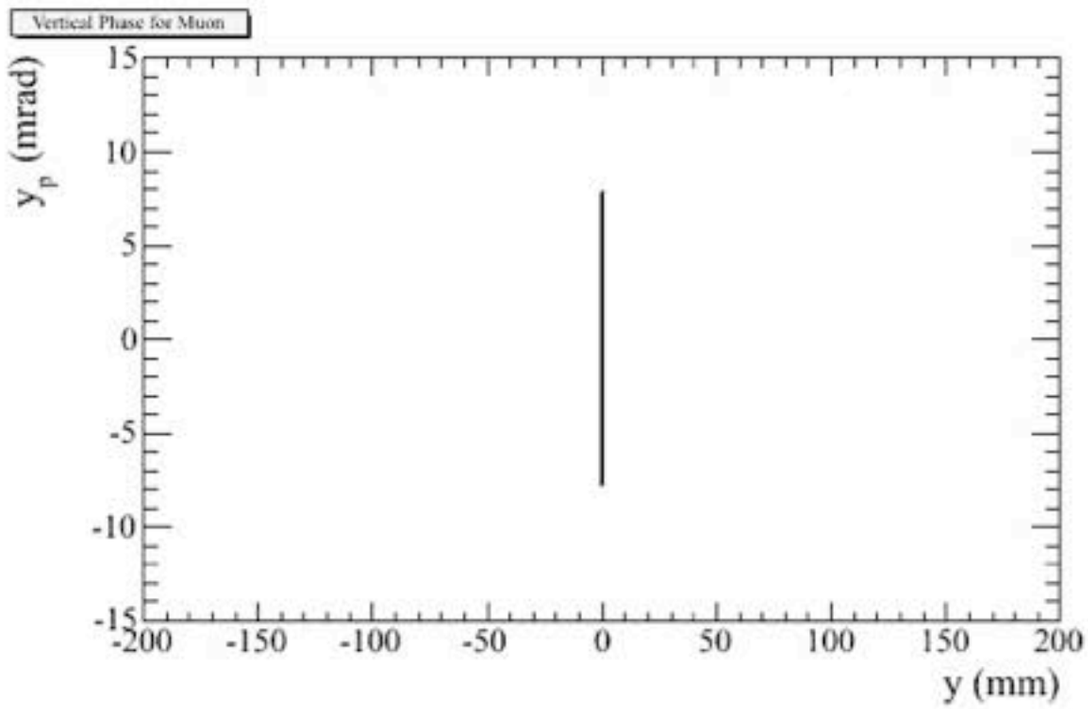


muon from 5GeV/c pion decay with ε_T=0

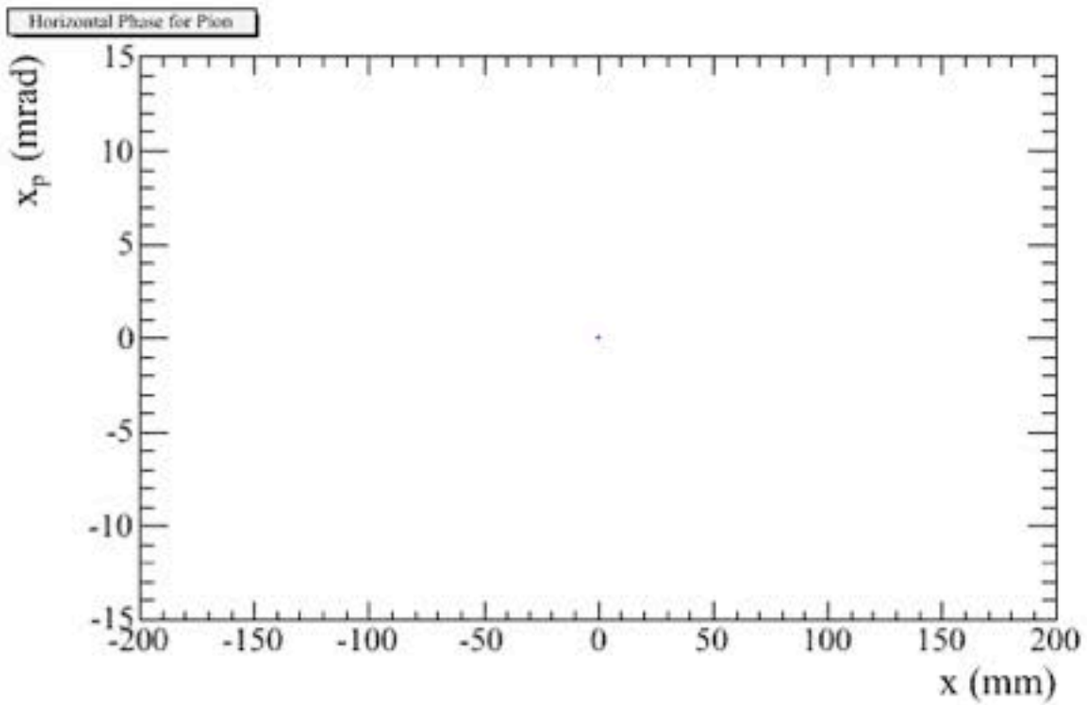


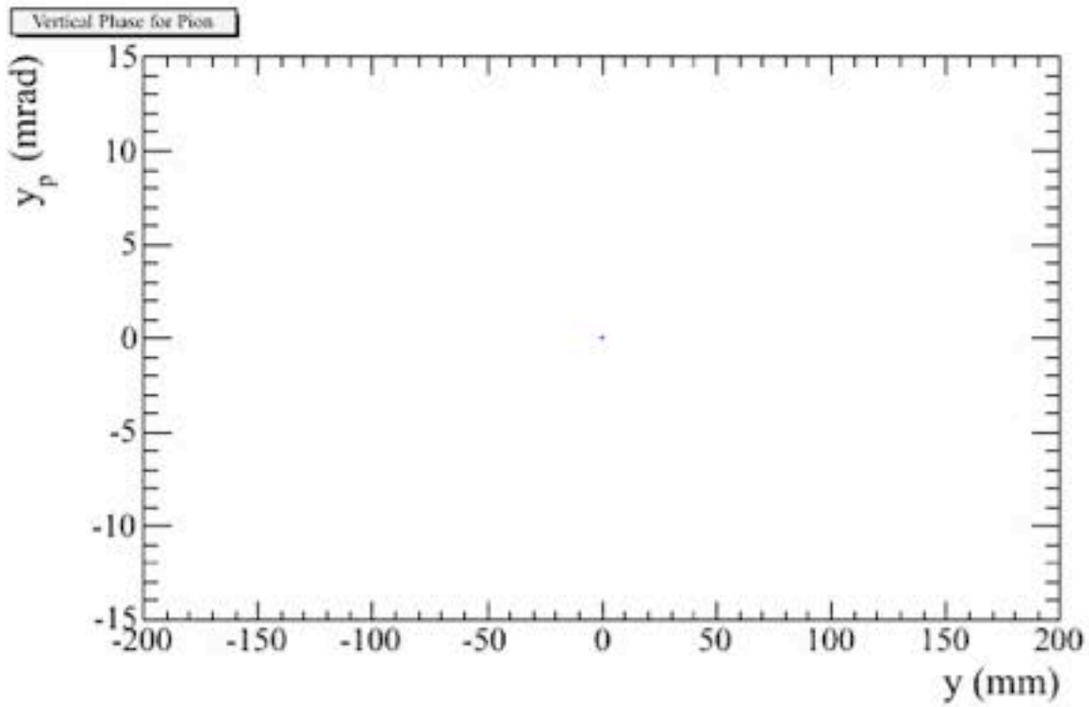


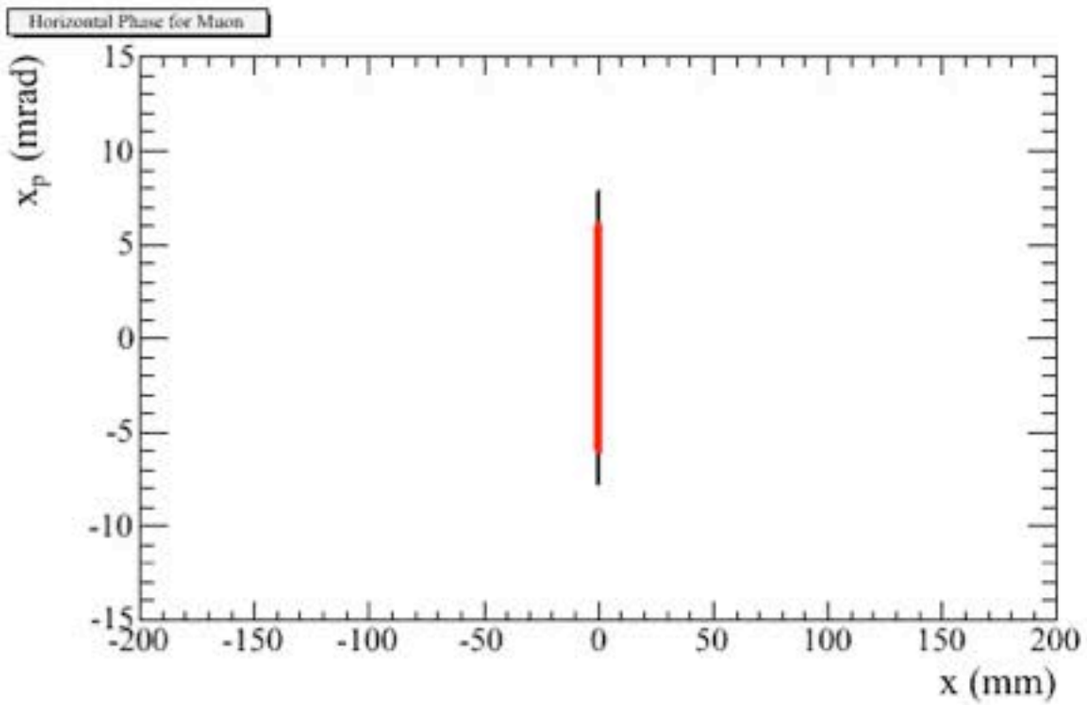


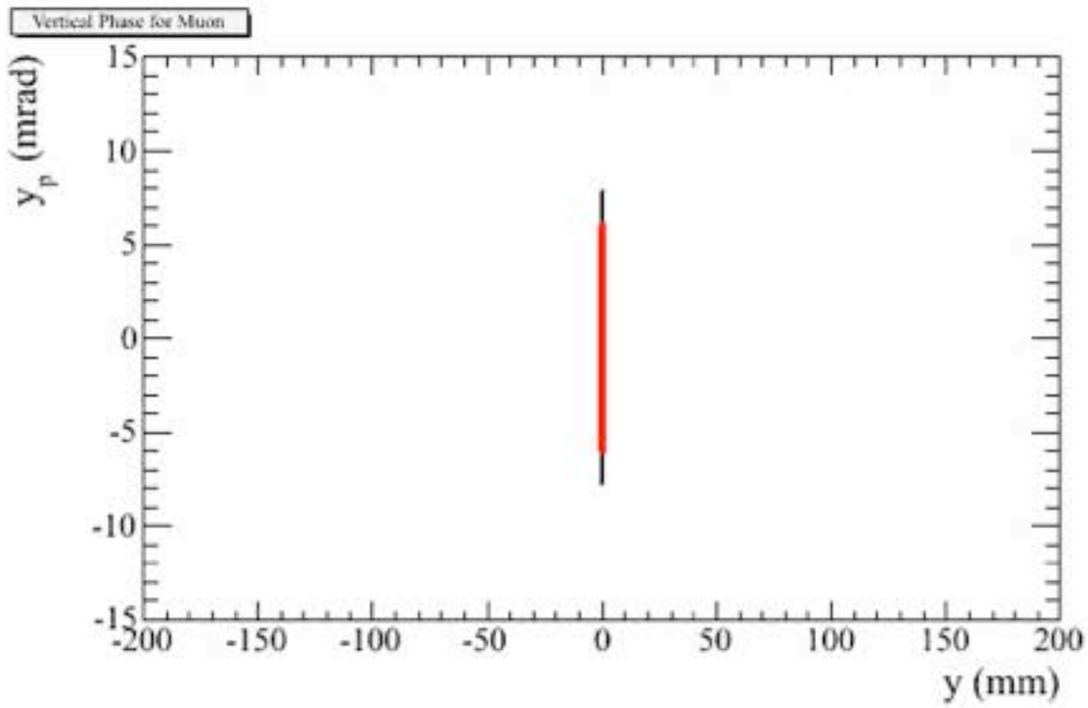


muon from 5GeV/c pion decay with ε_T=0



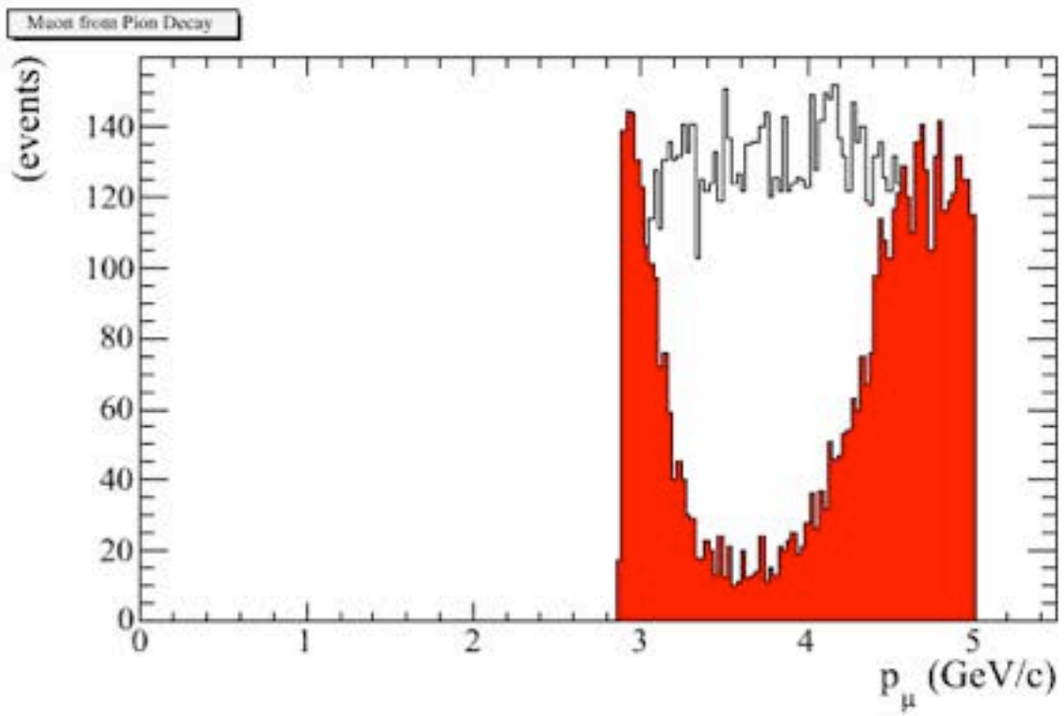


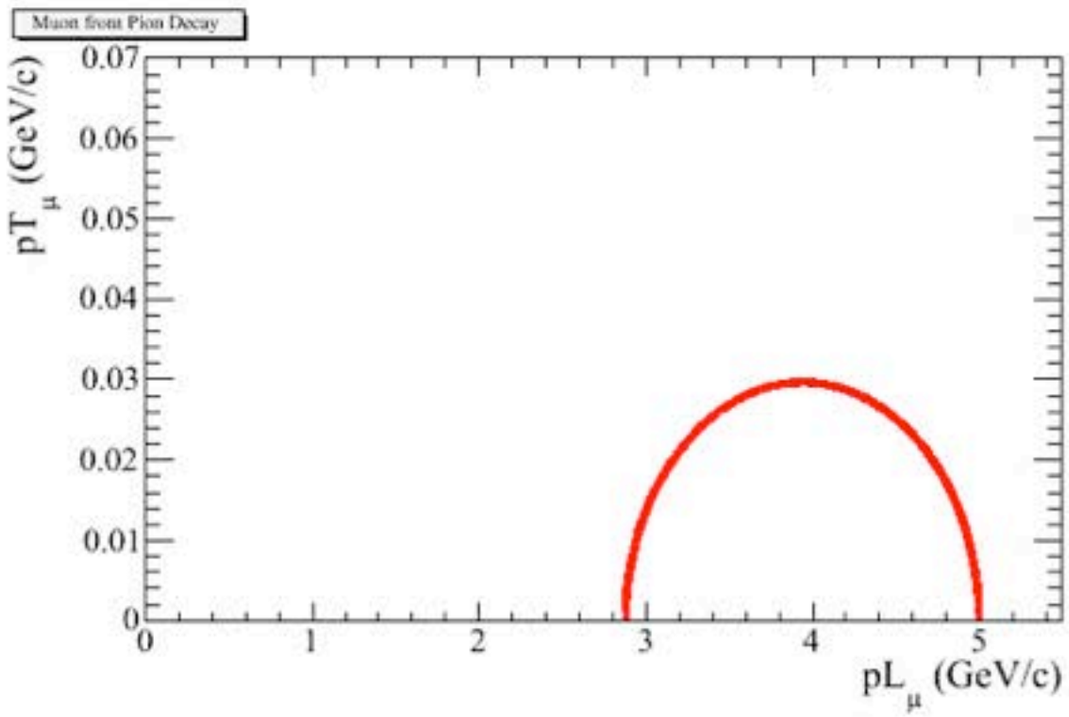


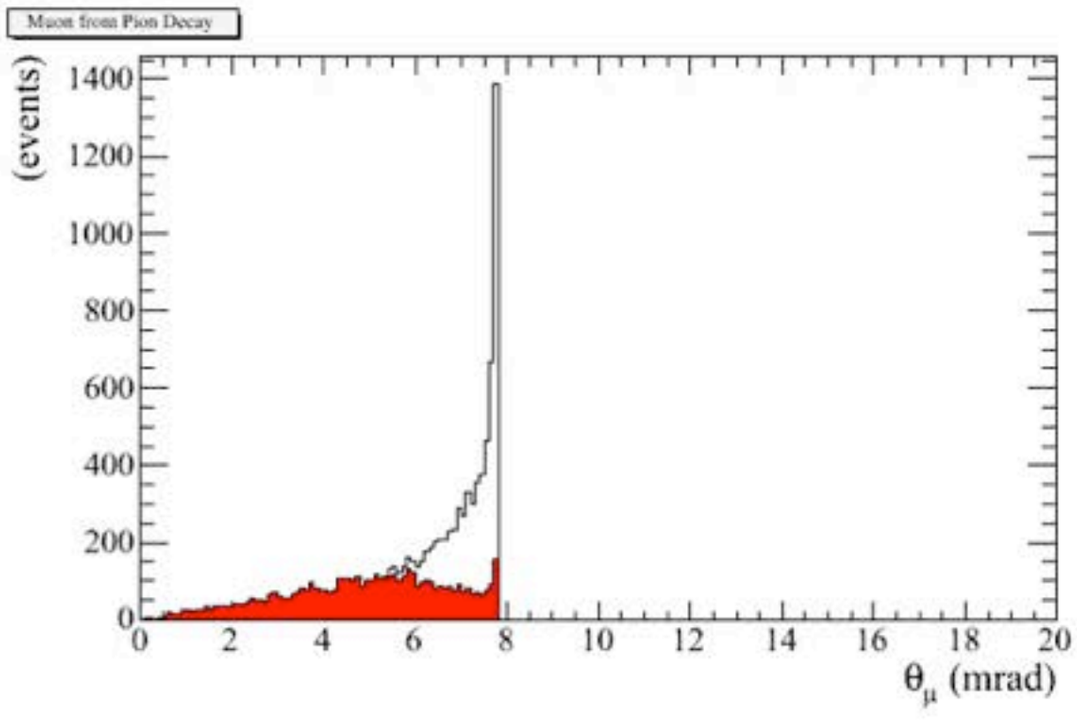


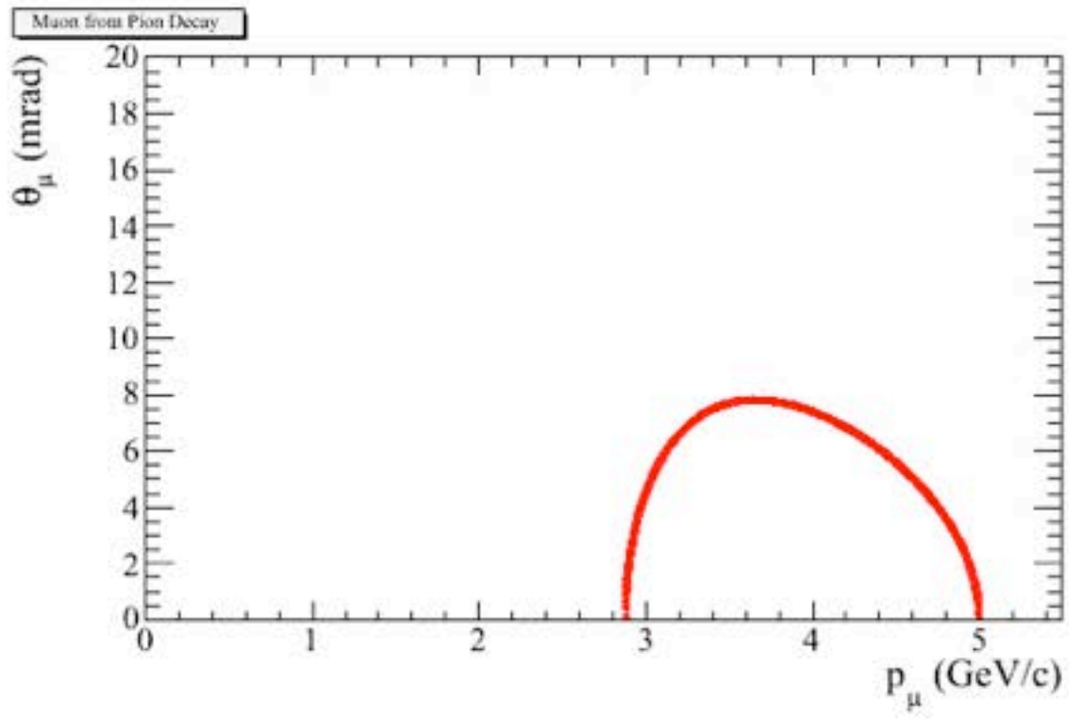
acceptance = 0.5

muon from 5GeV/c pion decay with $\varepsilon_{\pi}=0$

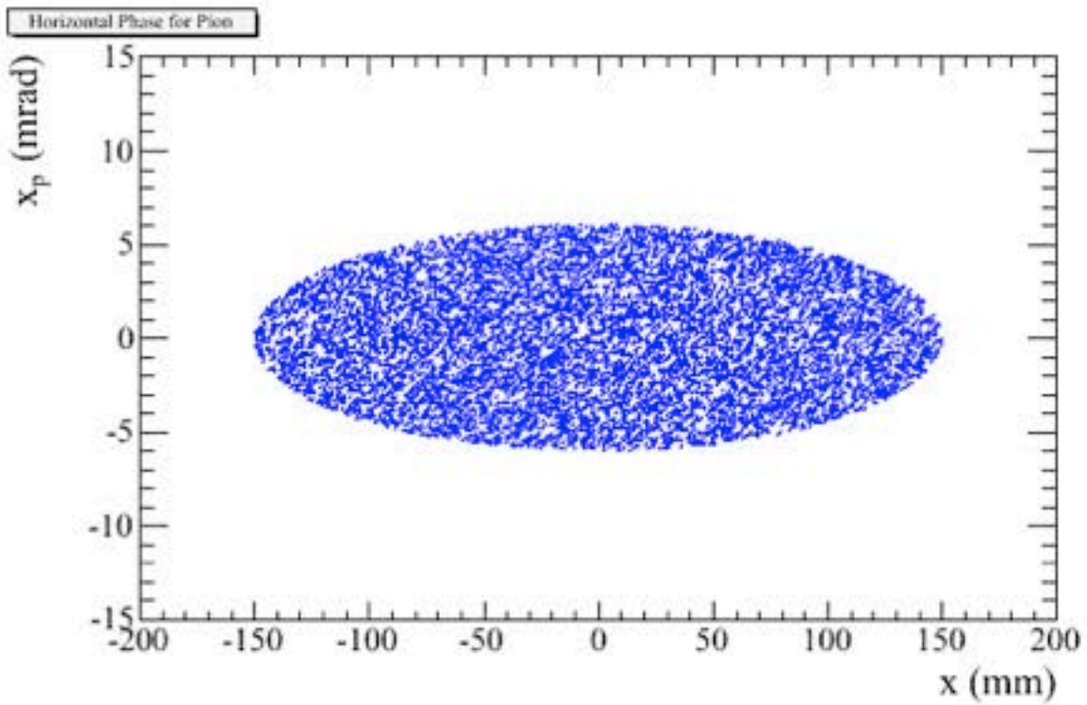


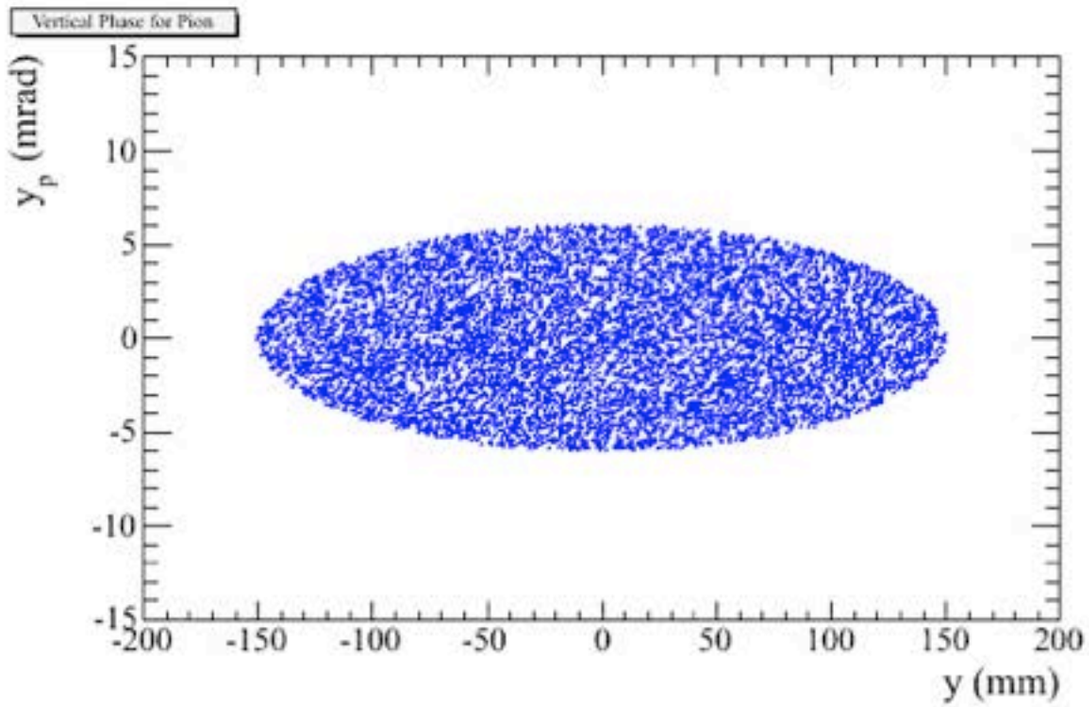


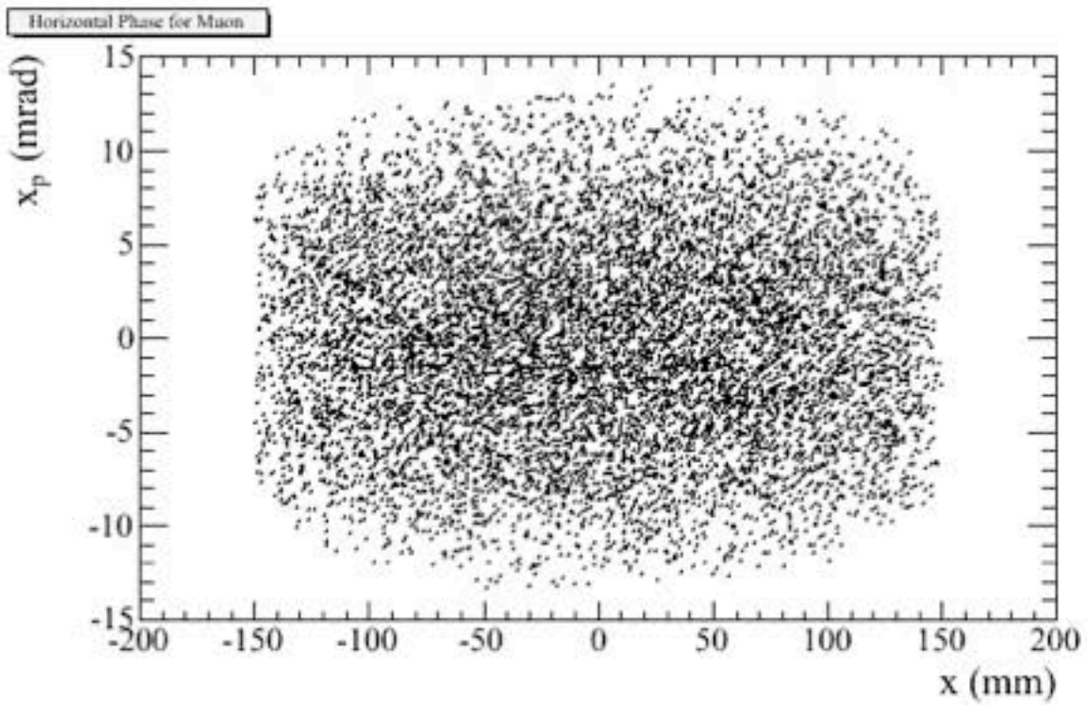


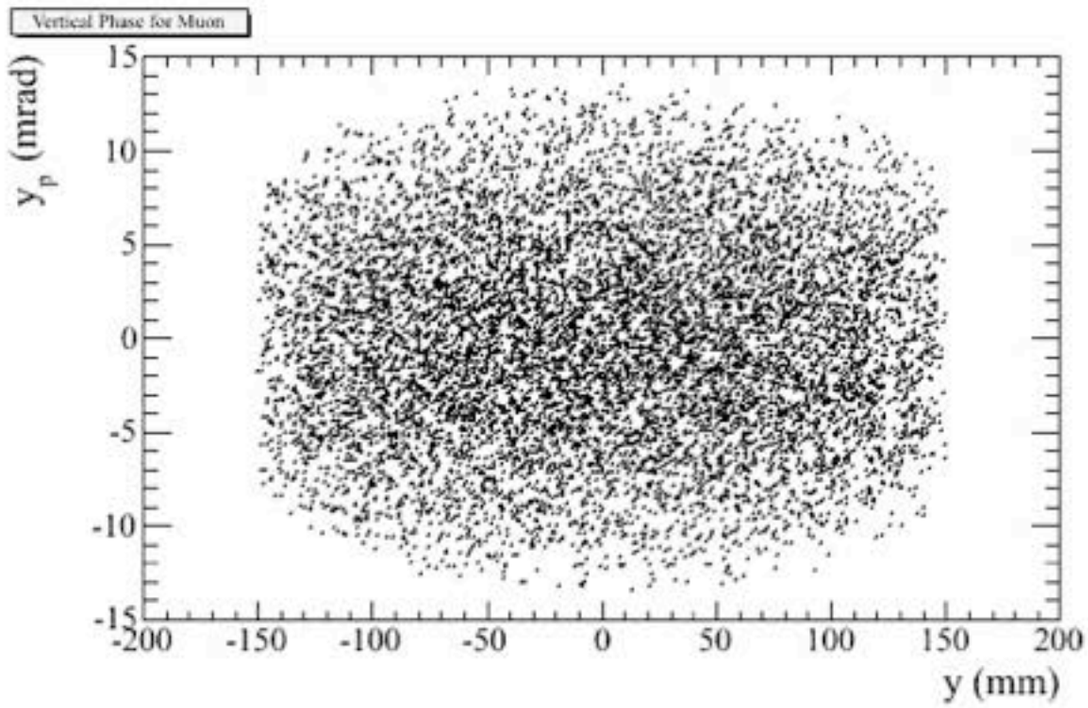


muon from 5GeV/c pion decay with ε_π=1000 π mm mrad

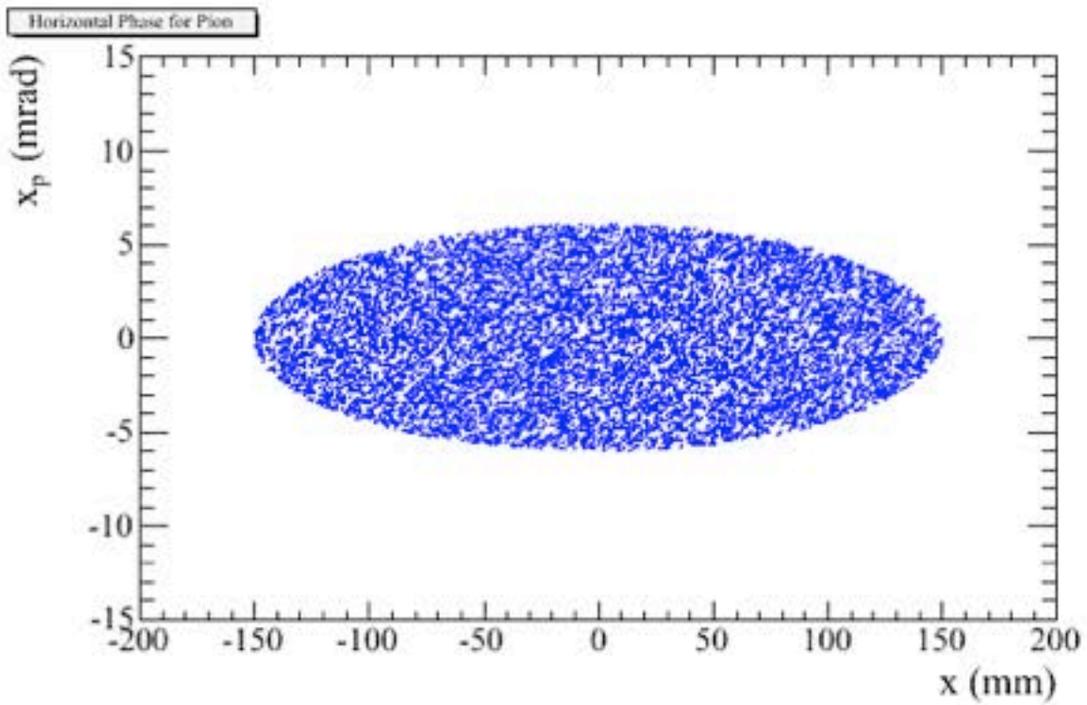


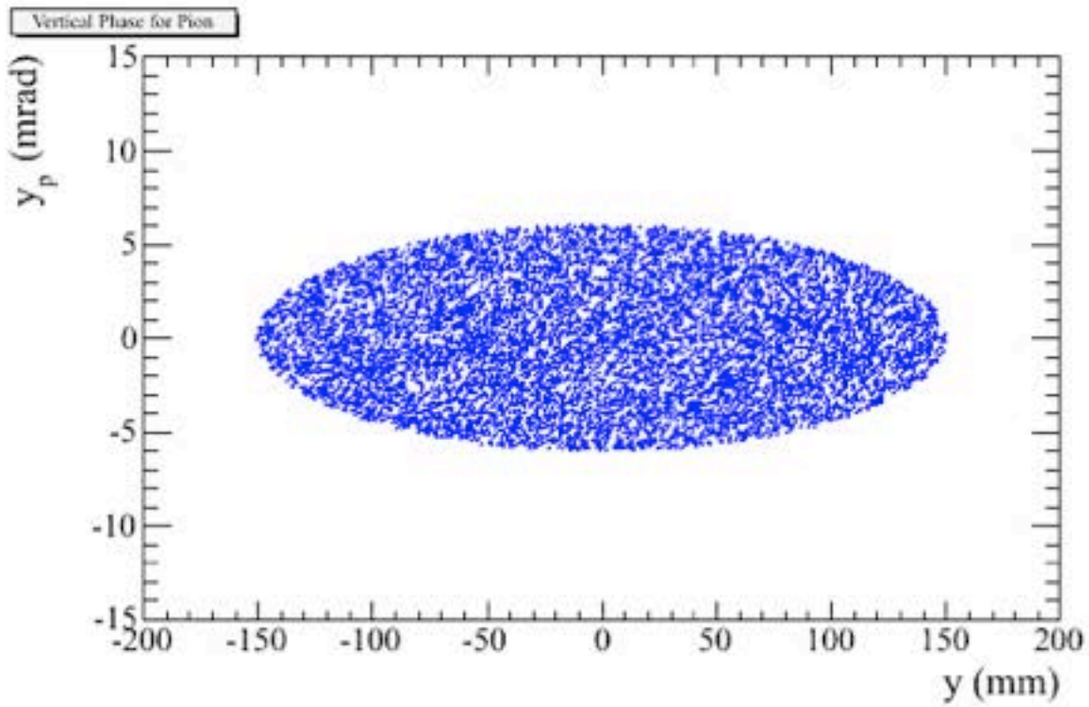


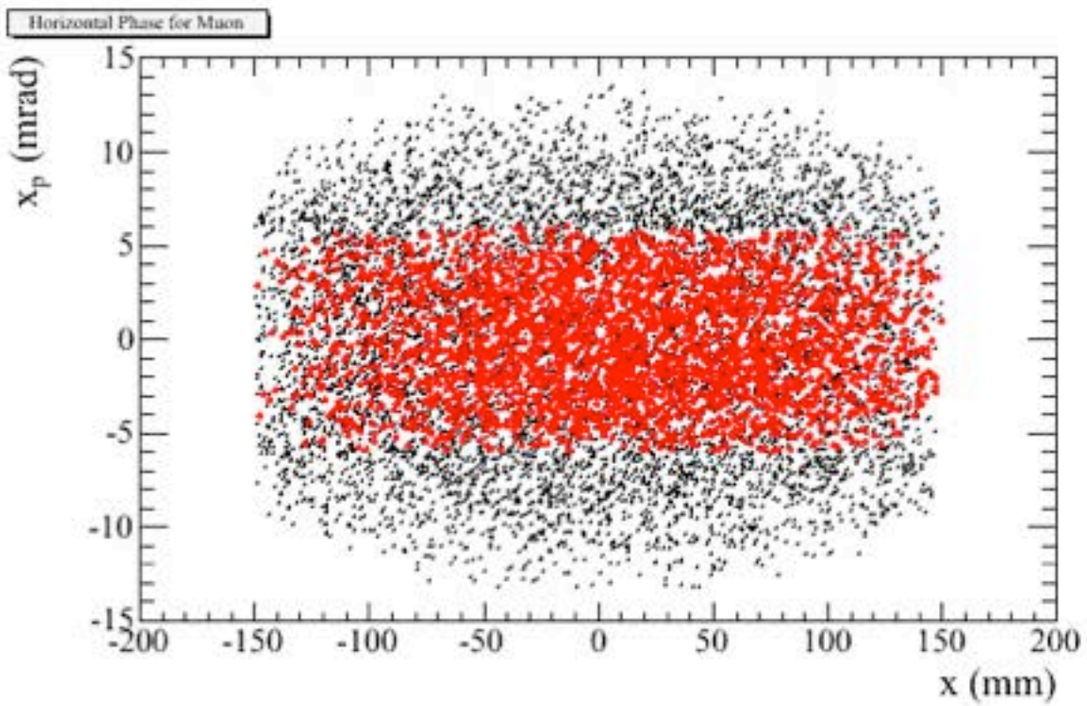


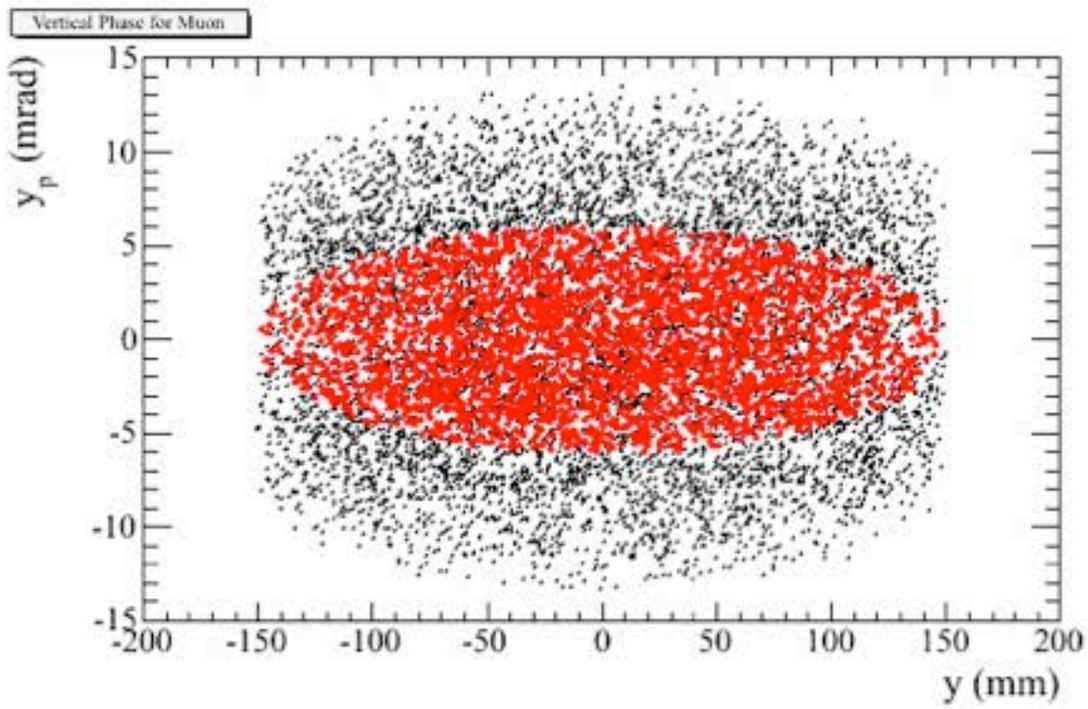


muon from 5GeV/c pion decay with ε_π=1000 π mm mrad



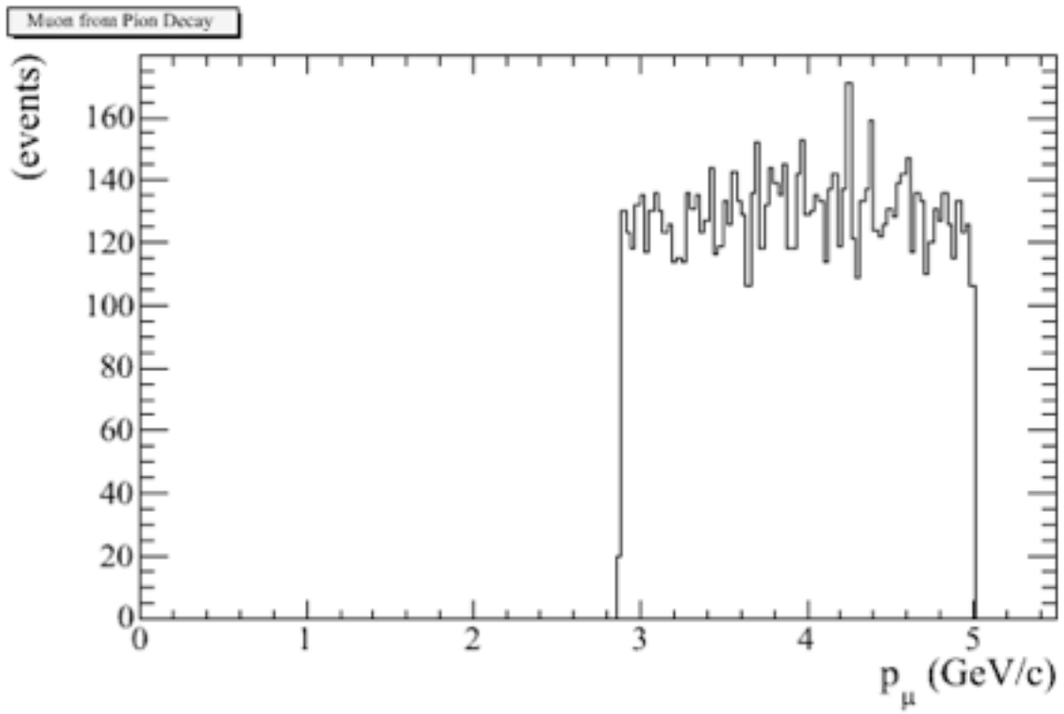


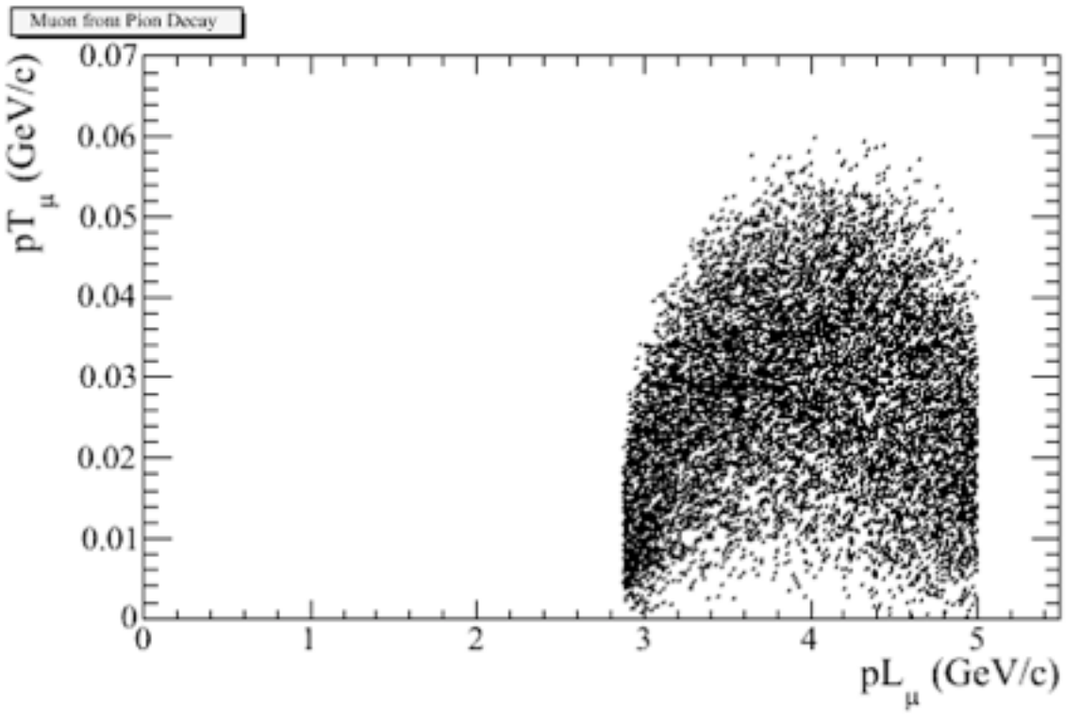


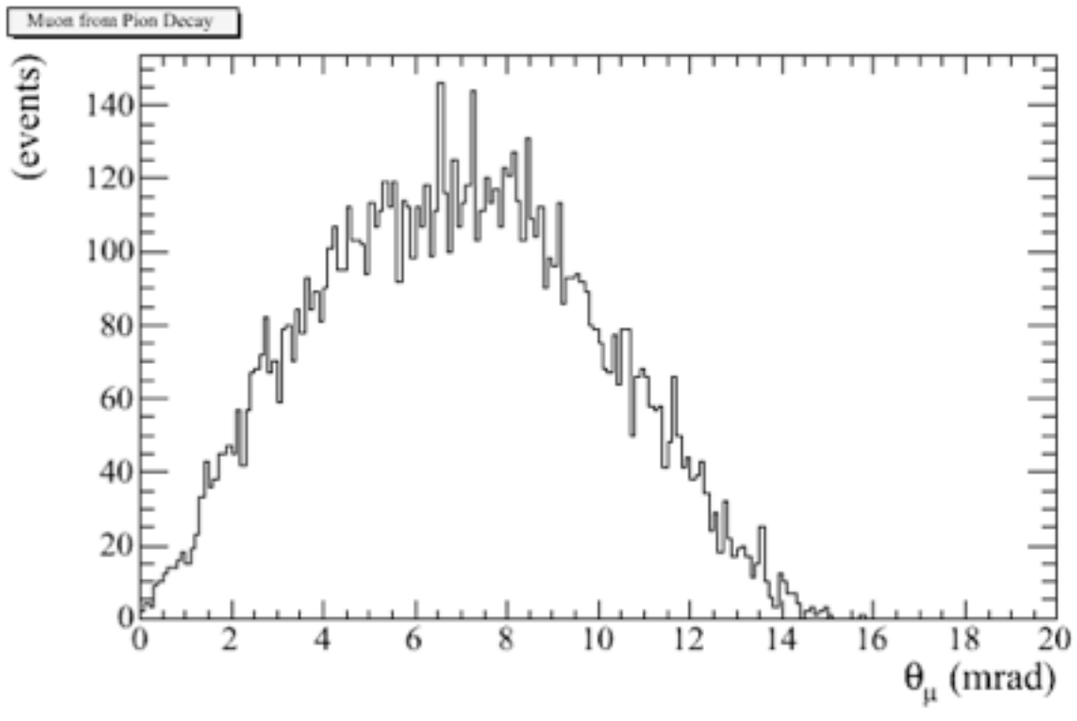


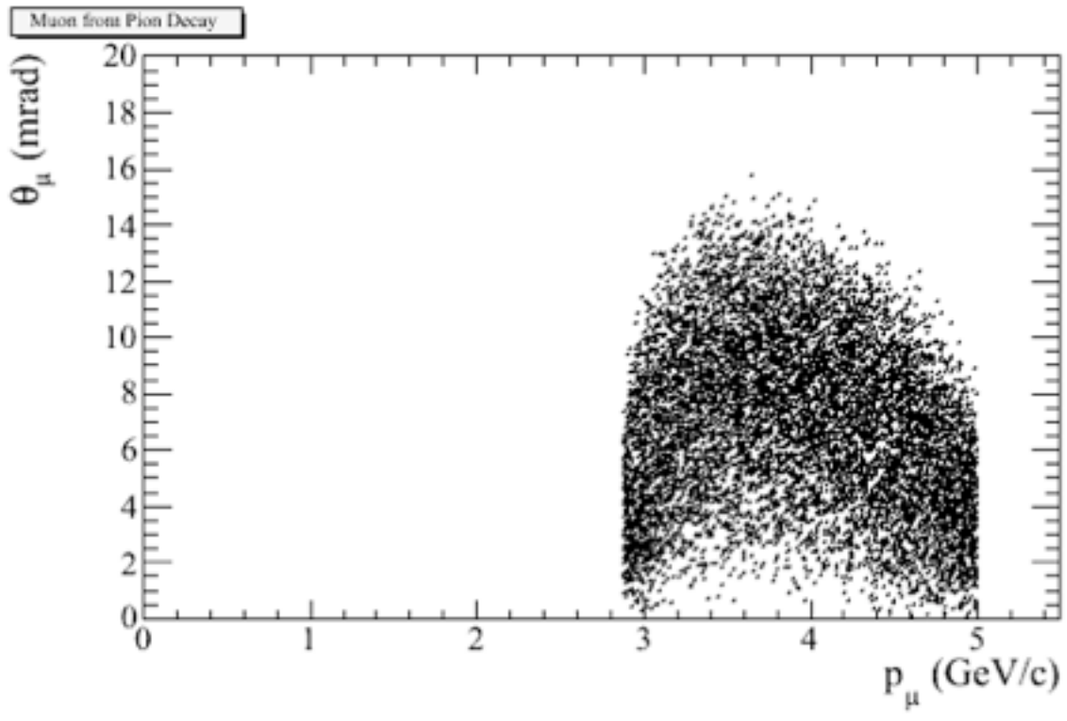
acceptance = 0.3

muon from 5GeV/c pion decay with ε_π=1000 π mm mrad

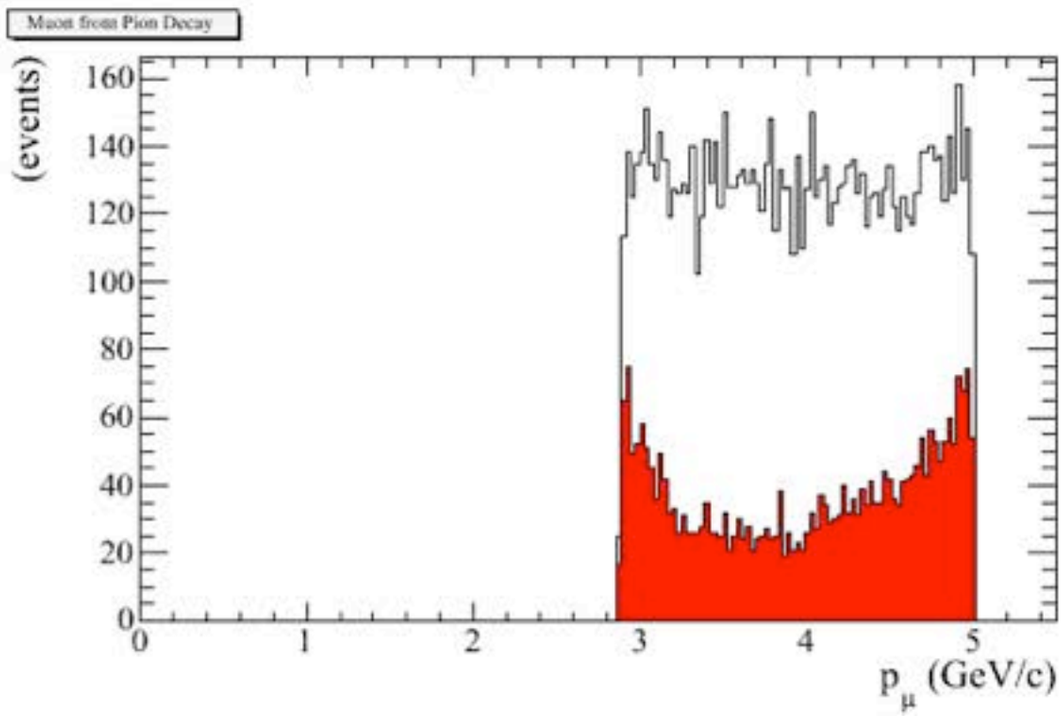


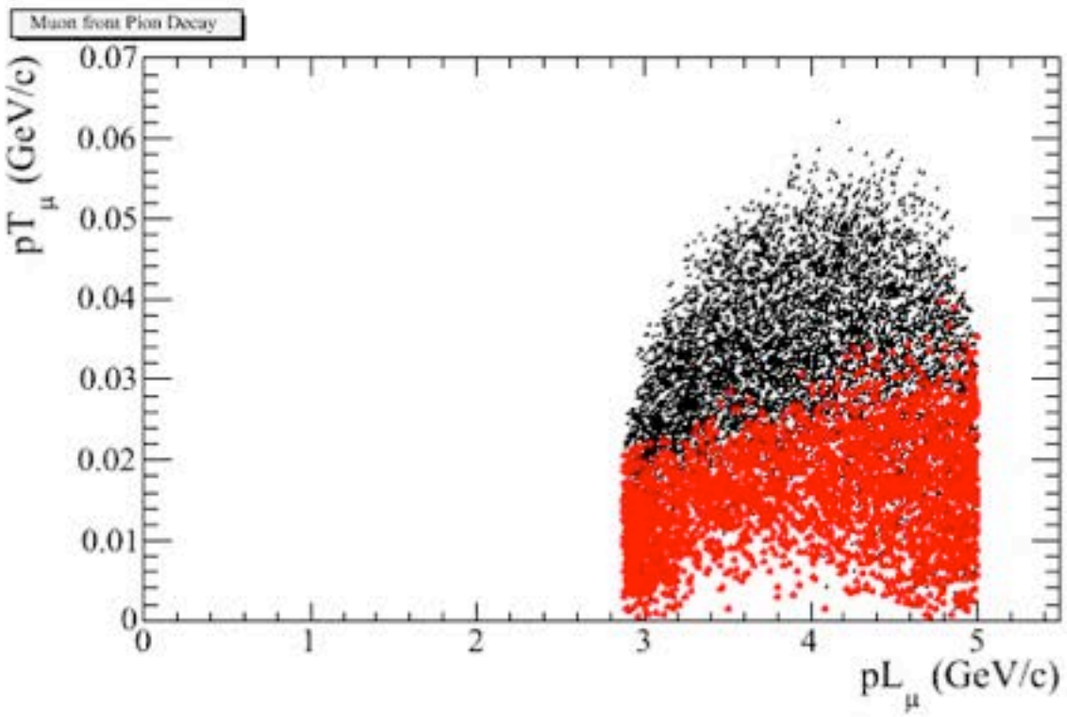


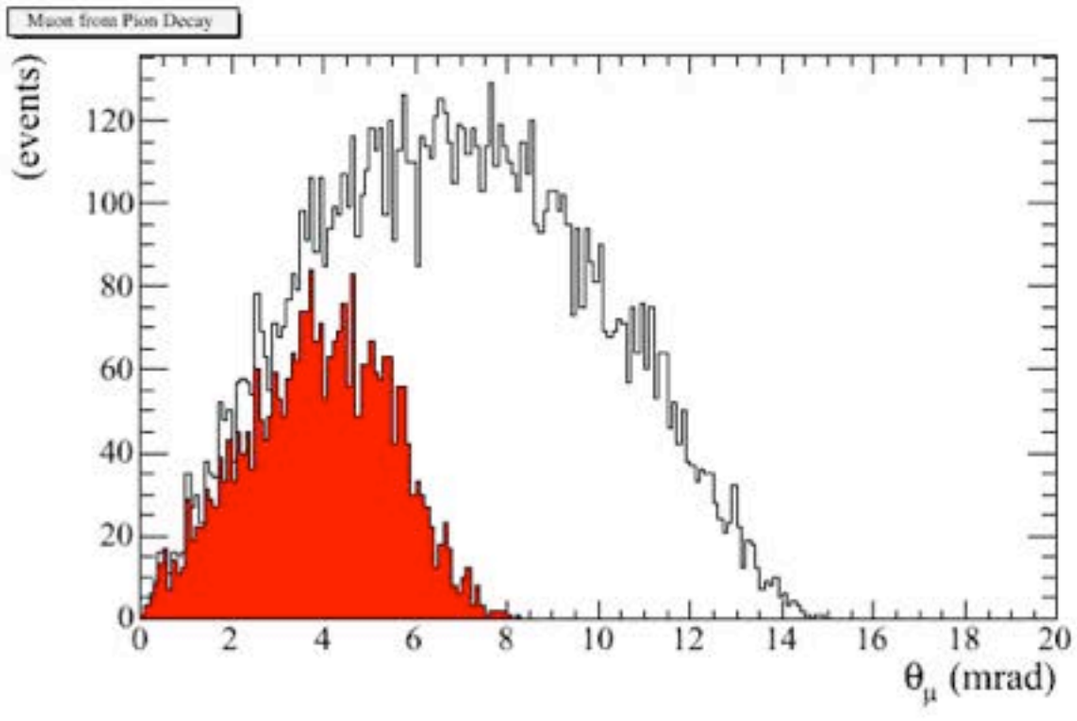


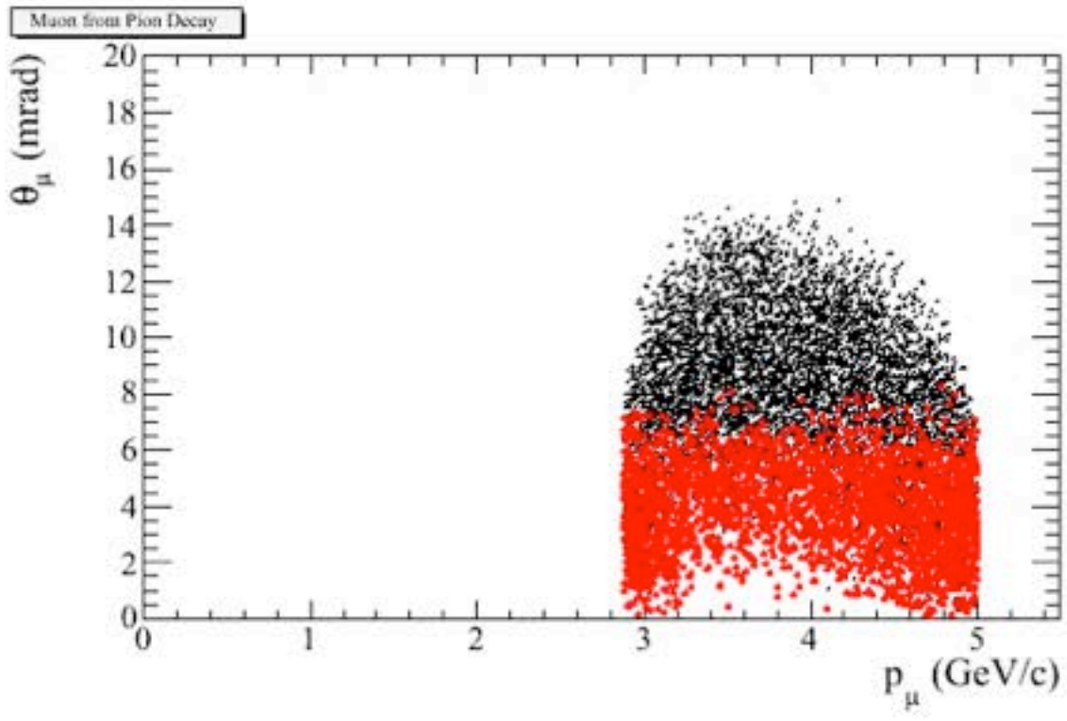


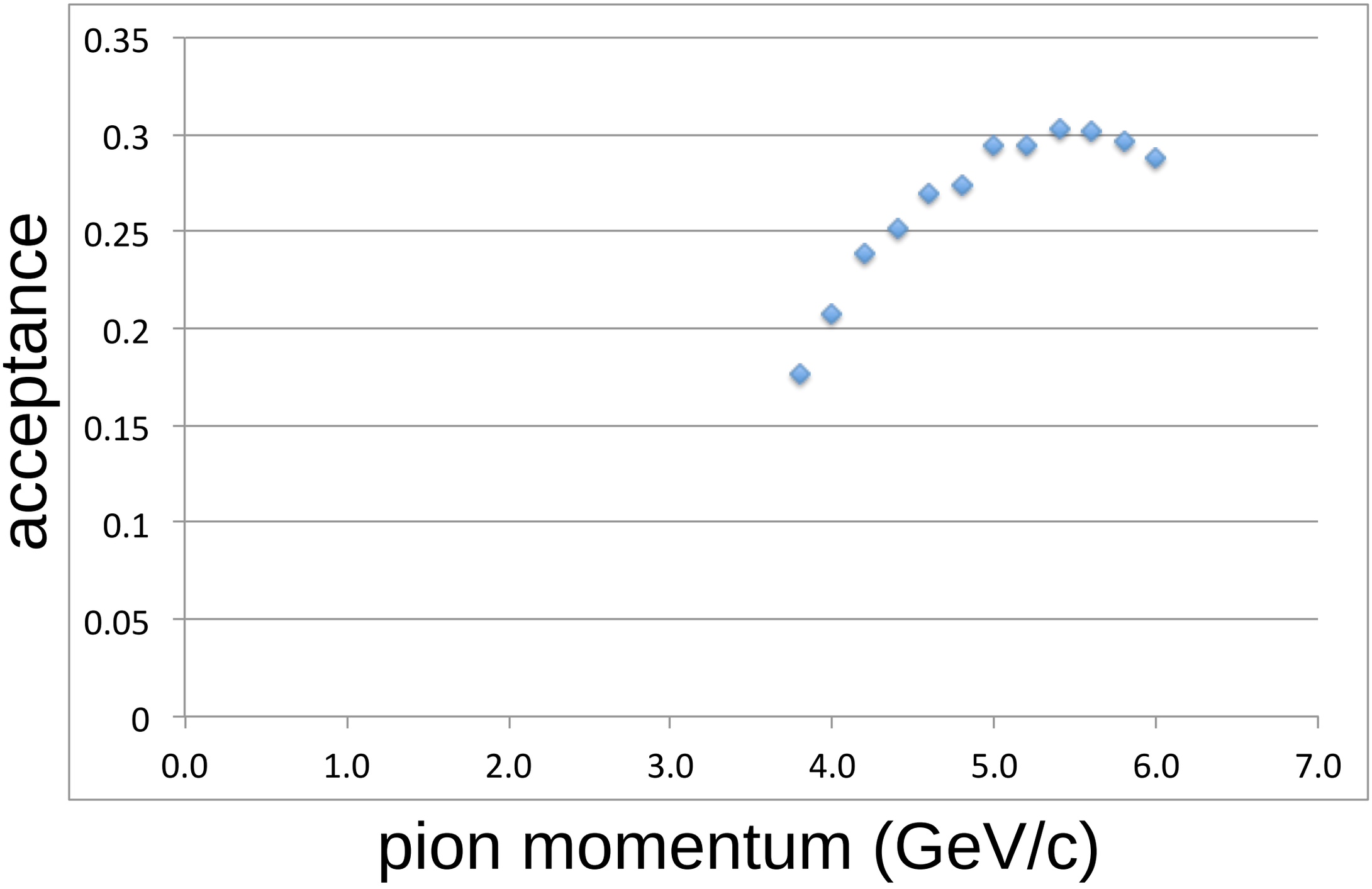
muon from 5GeV/c pion decay with ε_π=1000 π mm mrad










acceptance
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
pion momentum (GeV/c)

Conclusions

- **Advanced scaling Racetrack-FFAG rings have been designed by JB. Lagrange and Y. Mori as a muon decay ring for the vSTORM.**
  - 2GeV ring: 2GeV±16%, L_S=108m, L_A=50x2m
  - 3.8GeV ring: 3.8GeV/c±16%, L_S=240m, L_A=100x2m
- **Tracking by g4beamline for the Racetrack-FFAG rings has been performed. You need small maxStep(<5mm) and fine grid magnetic field maps to reasonable result.**
  - **Neutrino production for 2GeV RFFAG has been also tried with g4beamline. Profiles of the neutrino beam at L_D=26m was shown. They have good performance.**
  - **Tracking for 3.8GeV/c RFFAG is underway.**
- **Toward the proposal, we need to combine the simulation study by sharing information.**