Neutrino beam from a racetrack-FFAG muon decay ring for the VLENF

Akira SATO
Department of Physics, Osaka University
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VLENF Meeting by Ready Talk

Outline

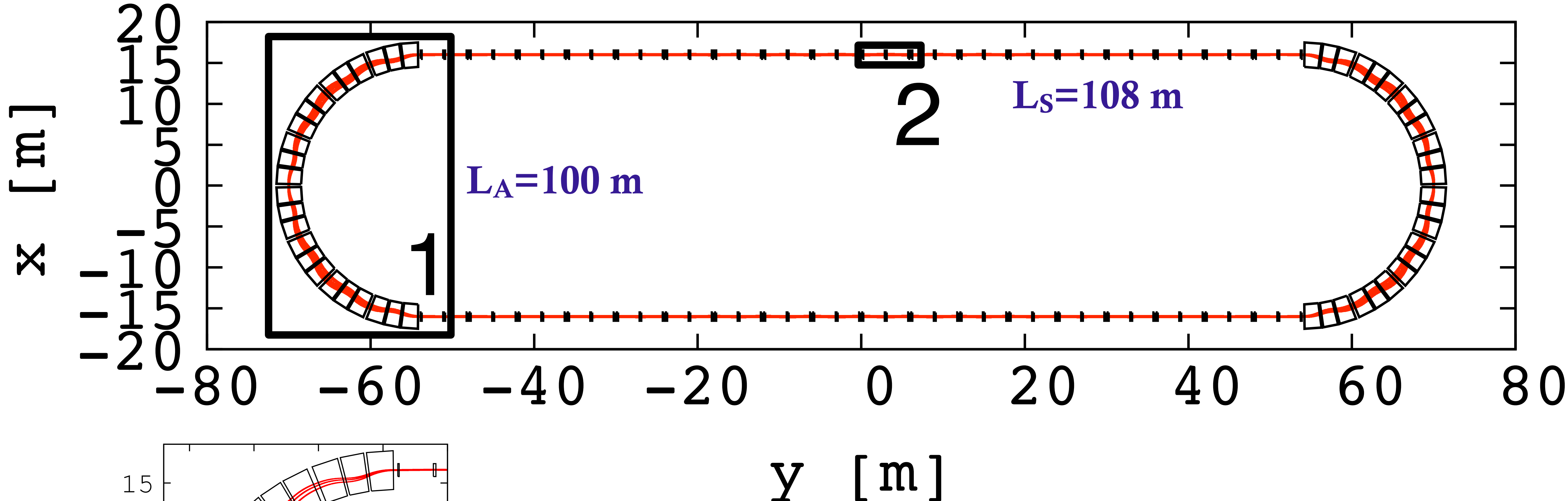
- **Racetrack-FFAG as a muon decay ring** (designed by JB. Lagrange)
  - Lattice design
  - Tracking results with JB’s original tracking code
- **Tracking with g4beamline**
  - Step size effects on the tracking
  - Comparison with the JB’s tracking results
- **Neutrino production in the ring with g4beamline**
  - E_μ=2.0GeV ± 0%
  - E_μ=2.0GeV ± 16%
- **Conclusions**

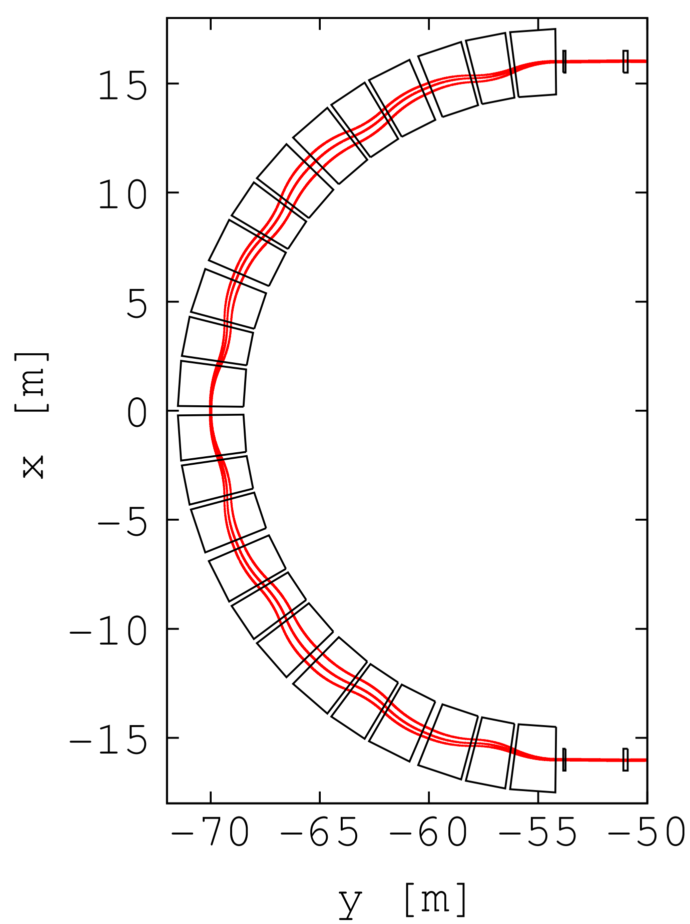
Muon decay Racetrack-FFAG ring for VLENF (Eμ=2GeV)

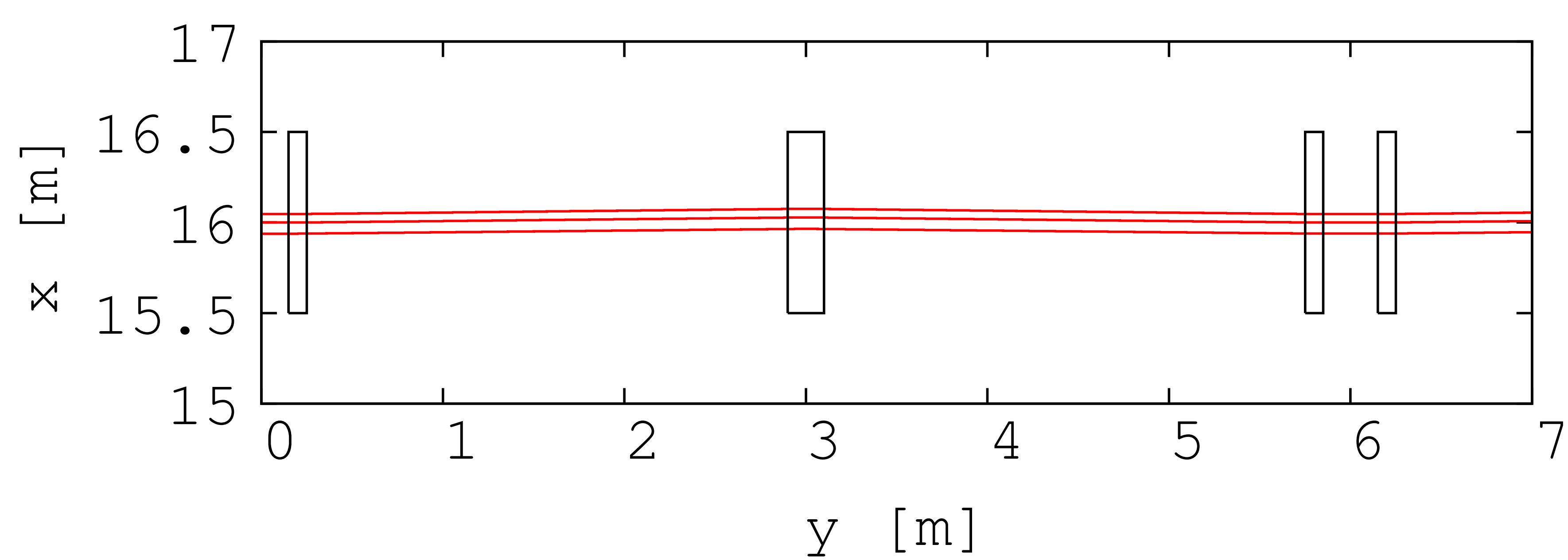
designed by JB. Lagrange (KURRI)

JB's Lattice for E_μ=2GeV, $\Delta p/p_0$=±16%

Advanced Scaling FFAG Muon decay ring with long straight sections.





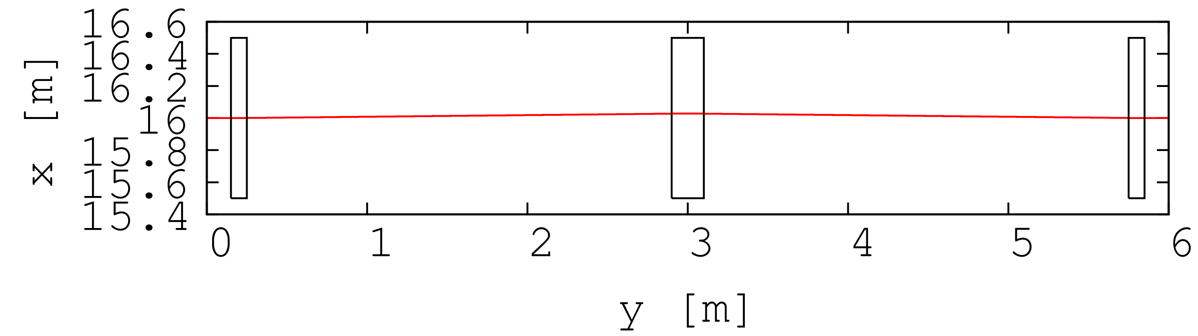


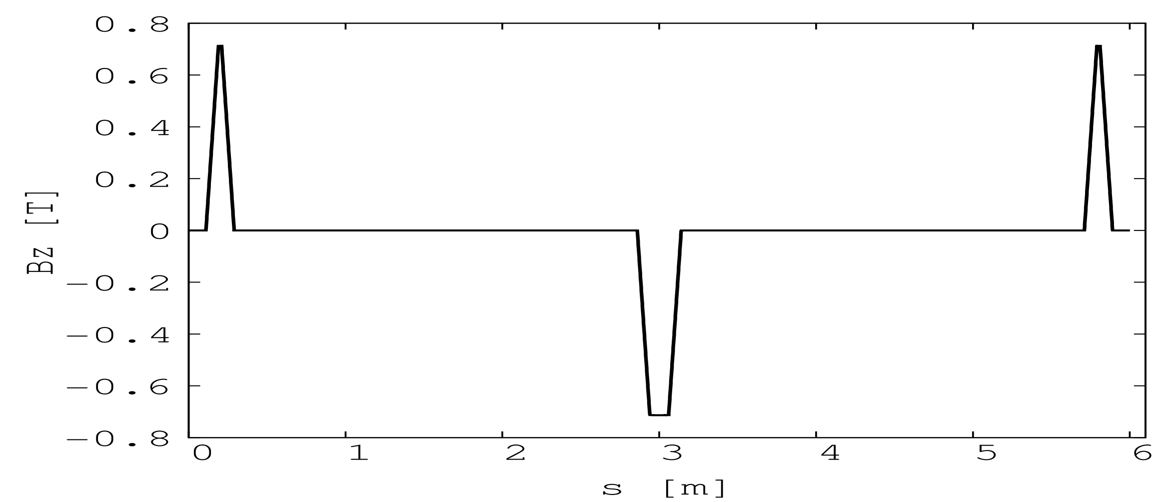
from JB. Lagrange, acc-kurri-1119-01-2011

JB's Lattice for E_μ=2GeV: Straight Section

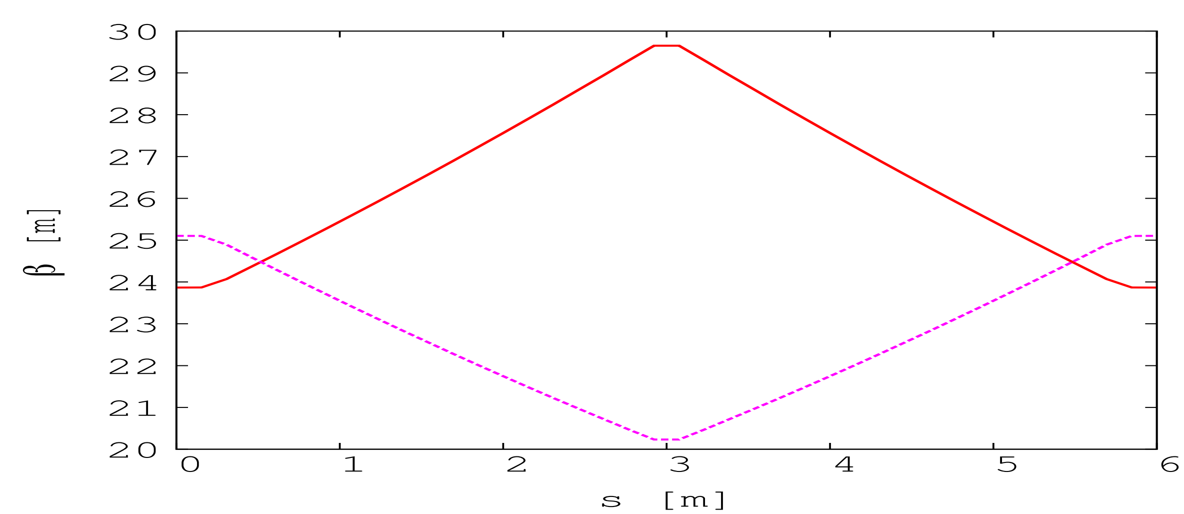
Cell type		DFD triplet
Number of cells in the ring		36
Cell length		6 m
x_0		16 m
m-value		$3.9\,\mathrm{m}^{-1}$
Packing factor		0.07
Collimators $(x_{min}, x_{max}, z_{max})$		(15.5 m, 16.5 m, 0.3 m)
Periodic cell dispersion		0.26 m
Horizontal phase advance		13.0 deg.
Vertical phase advance		15.2 deg.
D_1 magnet parameters		
	Magnet center	0.2 m
	Magnet length	0.1 m
	Fringe field fall off	Linear (Length: 0.04 m)
	$B_0(x_0 = 16\ m)$	0.712225 T
F magnet parameters		
	Magnet center	3 m
	Magnet length	0.2 m
	Fringe field fall off	Linear (Length: 0.04 m)
	$B_0(x_0 = 16\ m)$	-0.639761 T
D_2 magnet parameters		
	Magnet center	5.8 m
	Magnet length	0.1 m
	Fringe field fall off	Linear (Length: 0.04 m)
	$B_0(x_0 = 16\ m)$	0.712225 T

Table 1: Parameters of the straight scaling FFAG cell.





Vertical magnetic field for 2 GeV muon reference trajectory



Horizontal (plain red) and vertical (dotted purple) periodic betafunctions

$$B_{sz} = B_{0sz} e^{m(x-x_0)} \mathcal{F}, \quad B_{0sz} = B_{sz}(x_0).$$

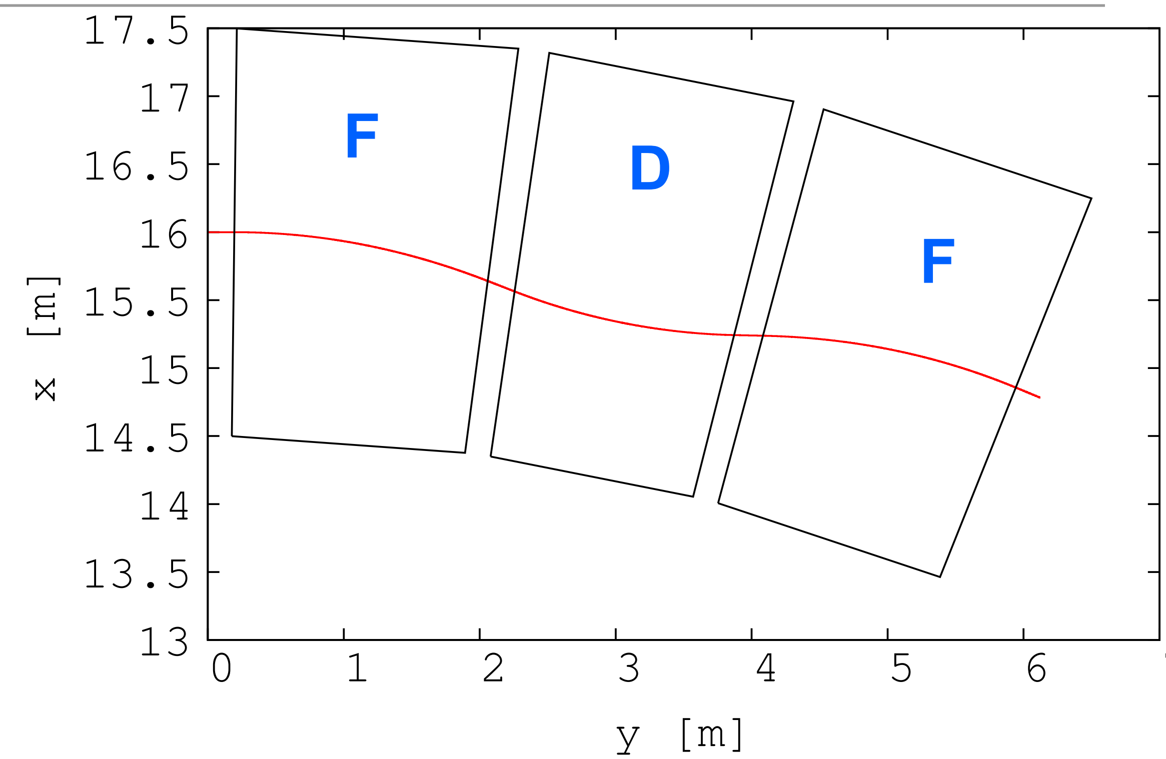
from JB. Lagrange, acc-kurri-1119-01-2011

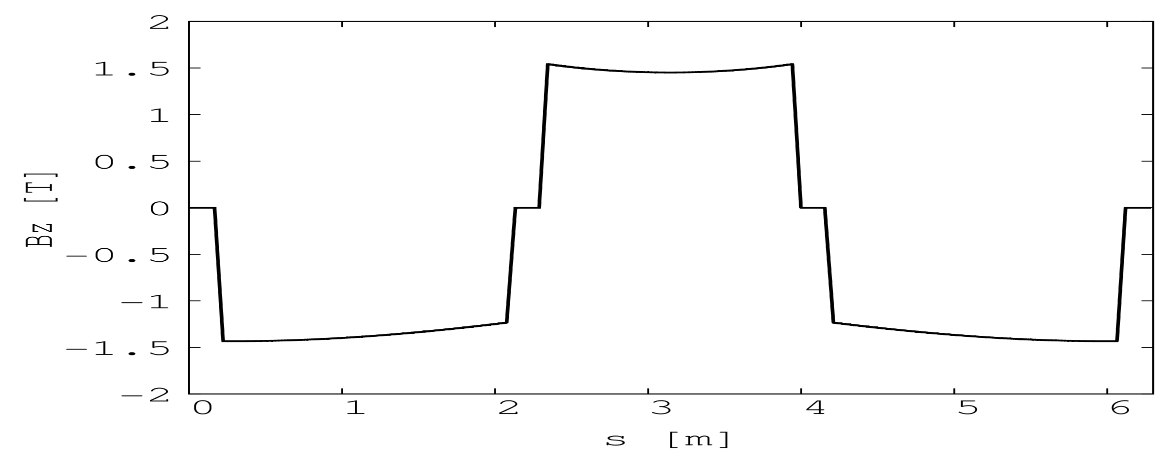
JB's Lattice for E_μ=2GeV: Circular Section

Cell type		FDF triplet
Number of cells in the ring		16
Cell opening angle		22.5 deg
r_0		16 m
k-value		10.85
Packing factor		0.9
Collimators $(r_{min}, r_{max}, z_{max})$		(14.5 m, 17.5 m, 0.3 m)
Periodic cell dispersion		1.35 m (at 2 GeV)
Horizontal phase advance		90. deg.
Vertical phase advance		22.5 deg.
F_1 magnet parameters		
	Magnet center	4.1 deg
	Magnet length	6.8 deg
	Fringe field fall off	Linear (Length: 0.1 deg)
	$B_0(r_0 = 16\ m)$	-1.430895 T
D magnet parameters		
	Magnet center	11.25 deg
	Magnet length	6.0 deg
	Fringe field fall off	Linear (Length: 0.1 deg)
	$B_0(r_0 = 16\ m)$	1.866669 T
F_2 magnet parameters		
	Magnet center	18.4 deg
	Magnet length	6.8 deg
	Fringe field fall off	Linear (Length: 0.1 deg)
	$B_0(r_0 = 16\ m)$	-1.430895 T

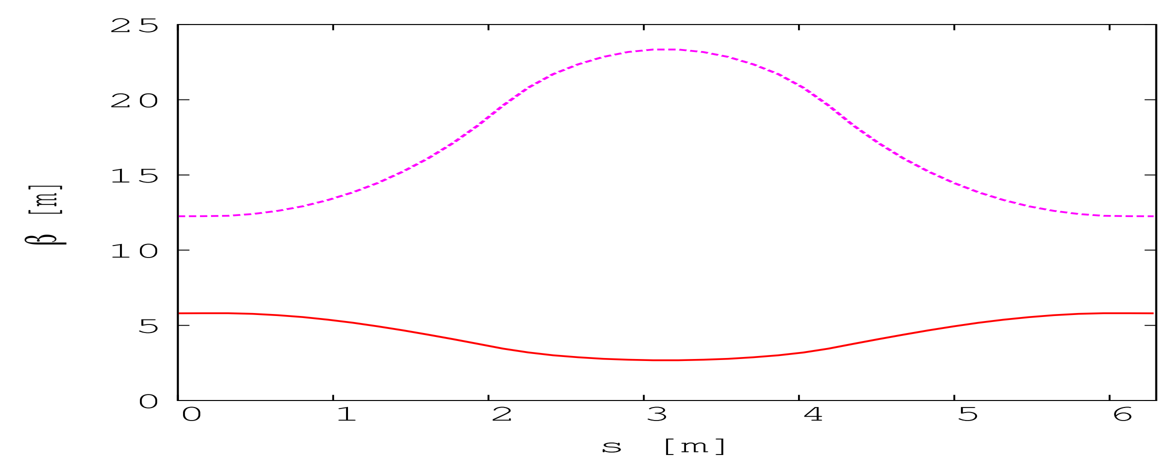
Table 2: Parameters of the circular scaling FFAG cell.

$$B_{cz} = B_{0cz} \left(\frac{r}{r_0}\right)^k \mathcal{F}, \qquad B_{0cz} = B_{cz}(r_0).$$





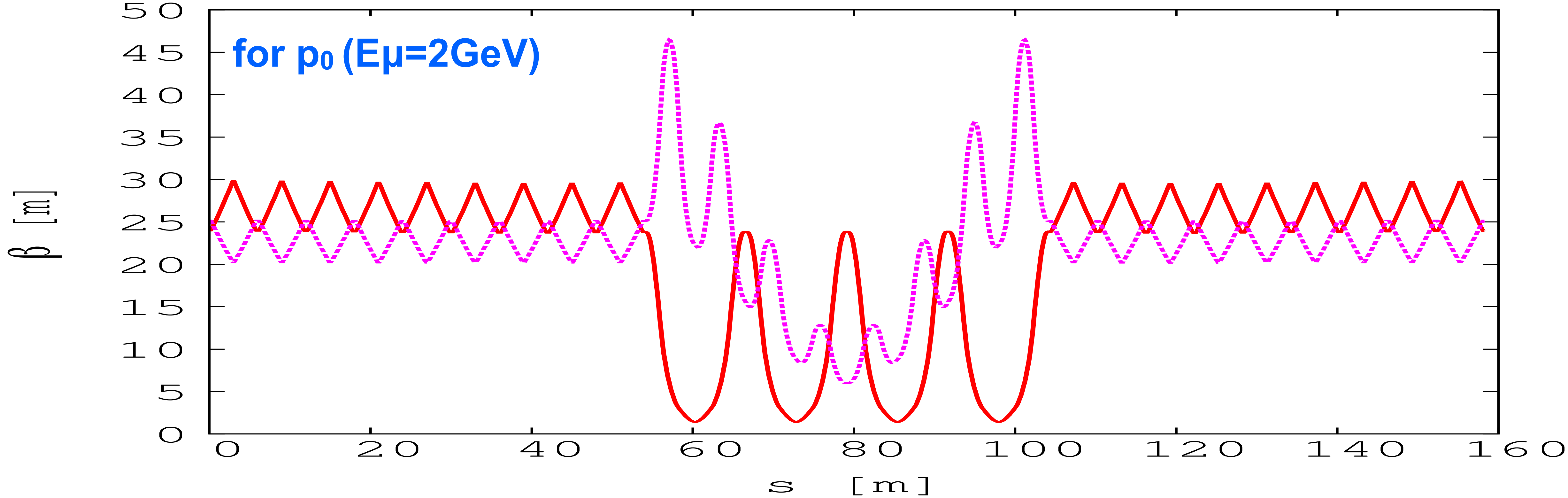
Vertical magnetic field for 2 GeV muon reference trajectory

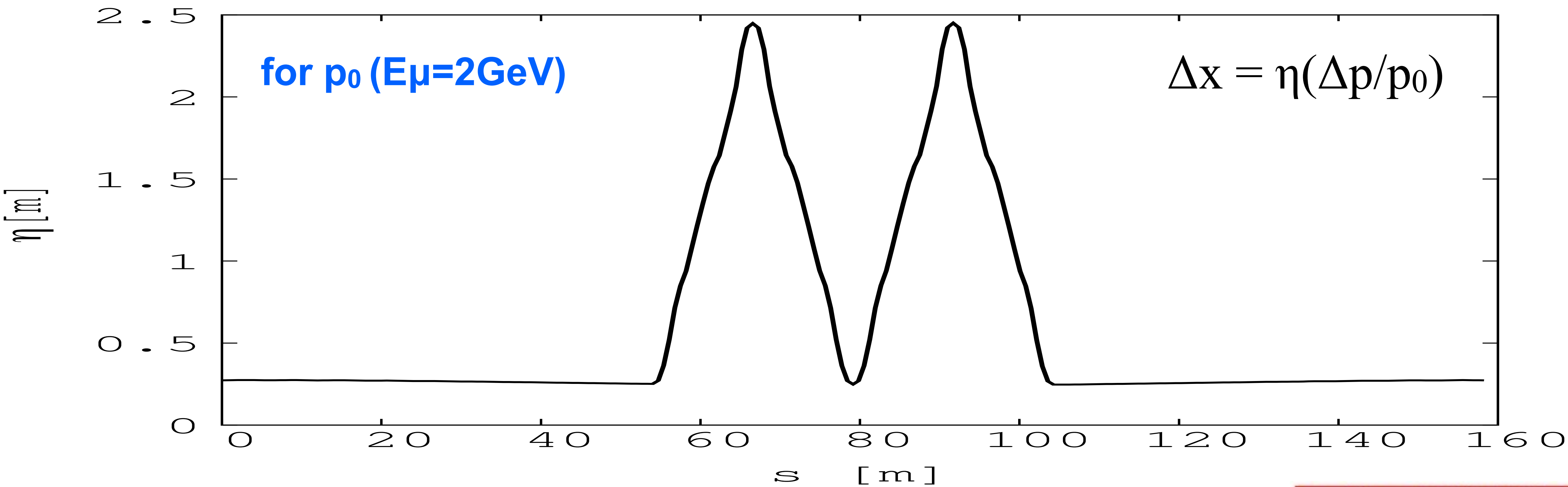


Horizontal (plain red) and vertical (dotted purple) periodic betafunctions

from JB. Lagrange, acc-kurri-1119-01-2011

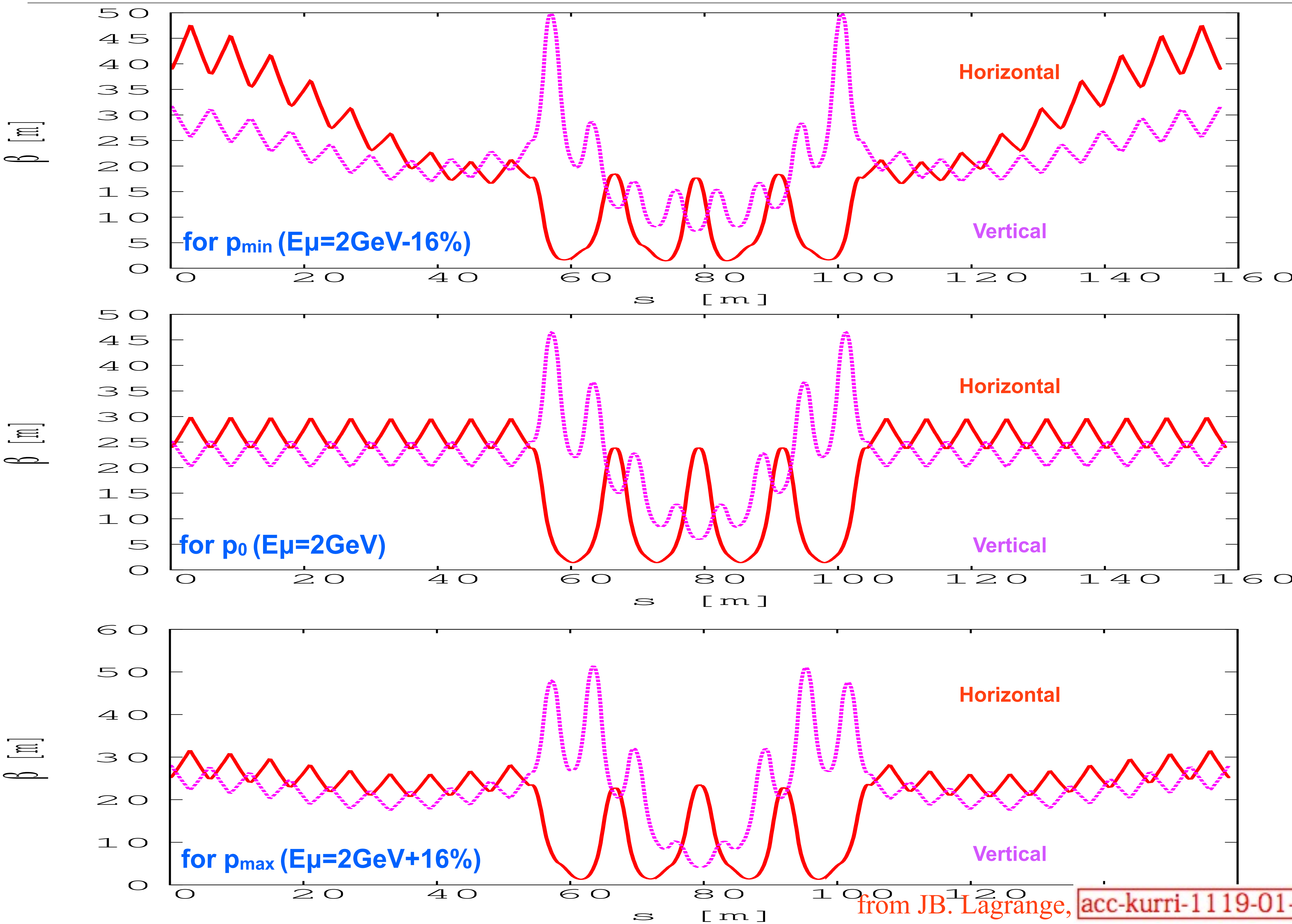
JB's Lattice for E_μ=2GeV: Beta and Dispersion





from JB. Lagrange, acc-kurri-1119-01-2011

JB's Lattice for E_μ=2GeV: Beta Function



from JB. Lagrange, acc-kurri-1119-01-2011

JB's Lattice for E_μ=2GeV: Tune Diagram

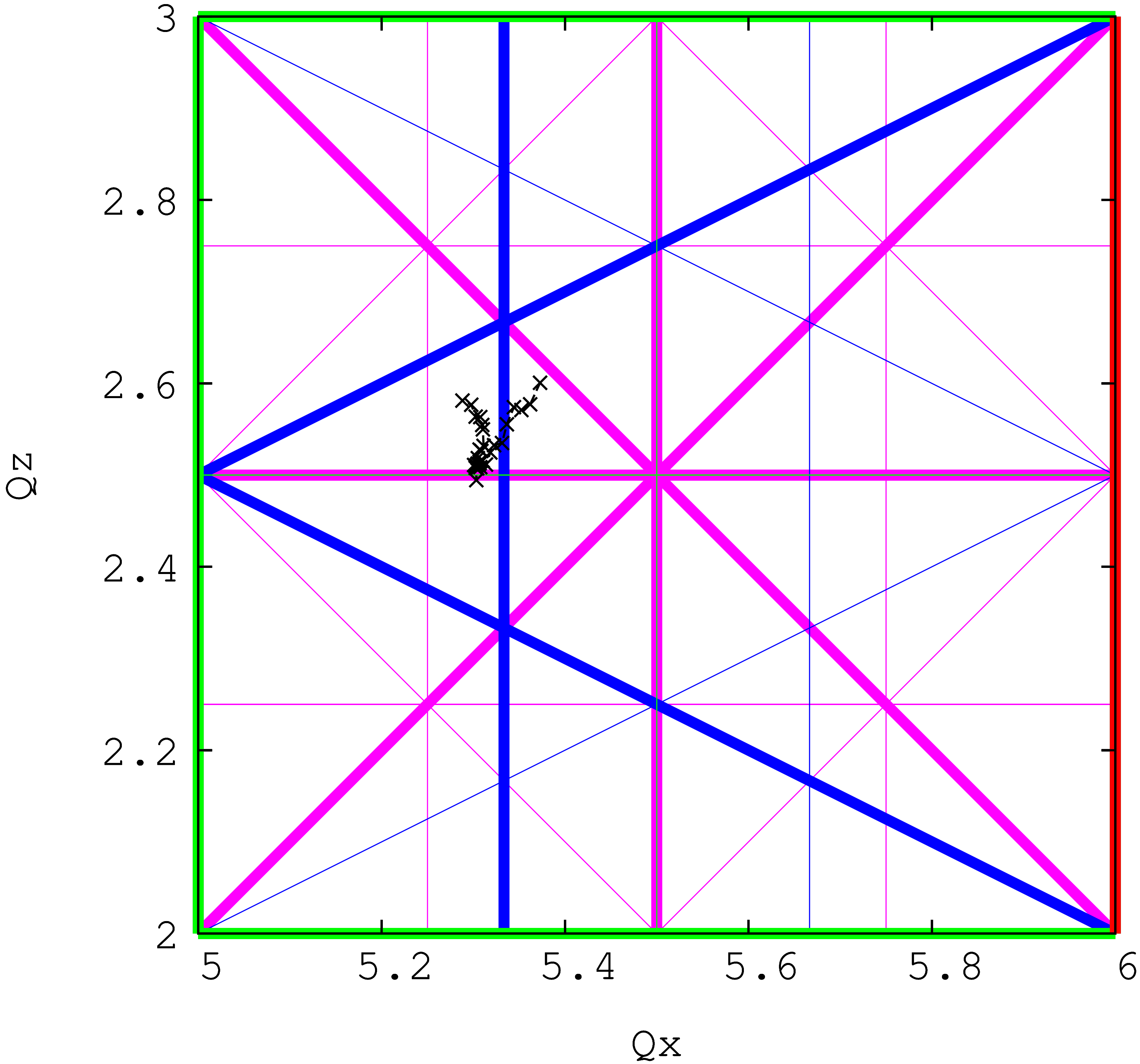


Figure 7: Tune diagram for muons from p_{min} to p_{max} ($\pm 16\%$ in momentum around 2.1 GeV/c). Integer (red), half-integer (green), third integer (blue) and fourth integer (purple) normal resonances are plotted. Structural resonances are in bold.

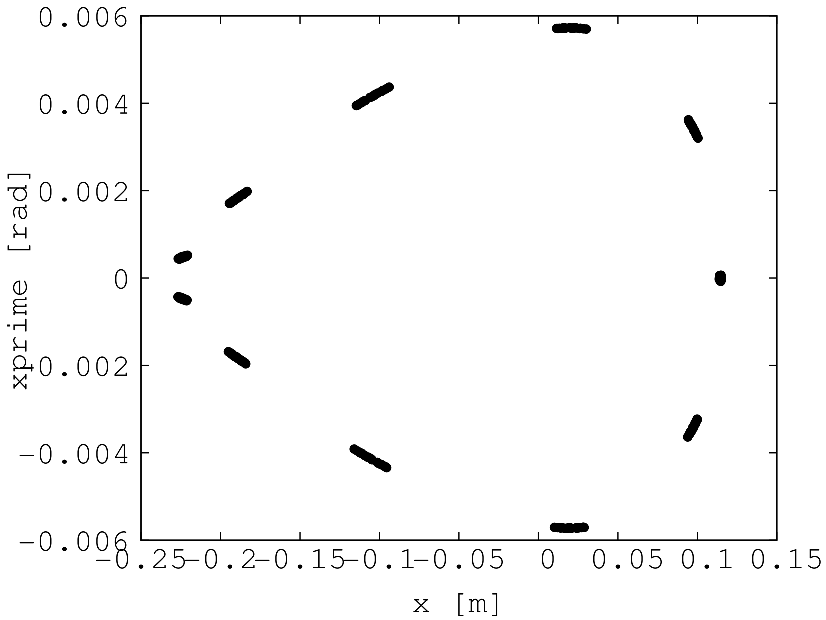
from JB. Lagrange, acc-kurri-1119-01-2011

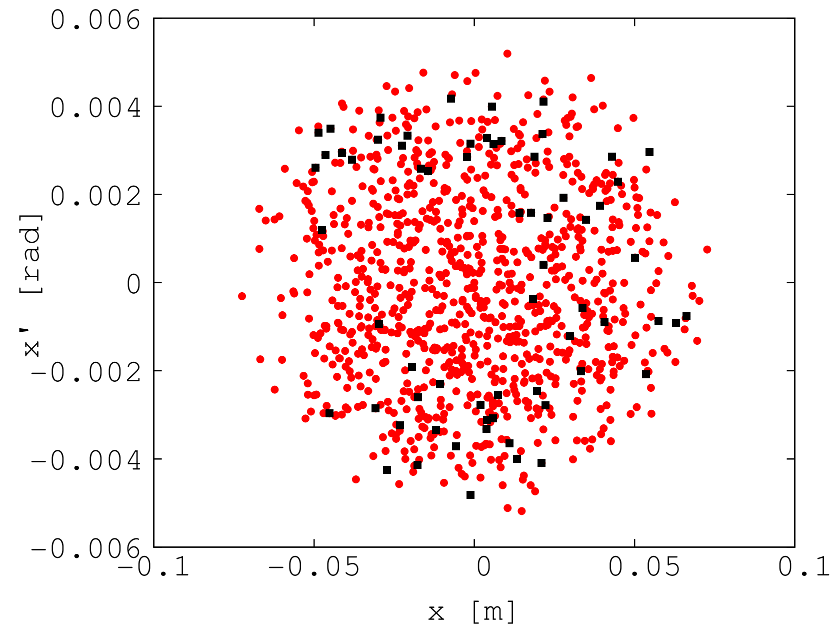
JB's Lattice for E_{μ}=2GeV: Acceptance

Max amplitude 100 turns for p_0

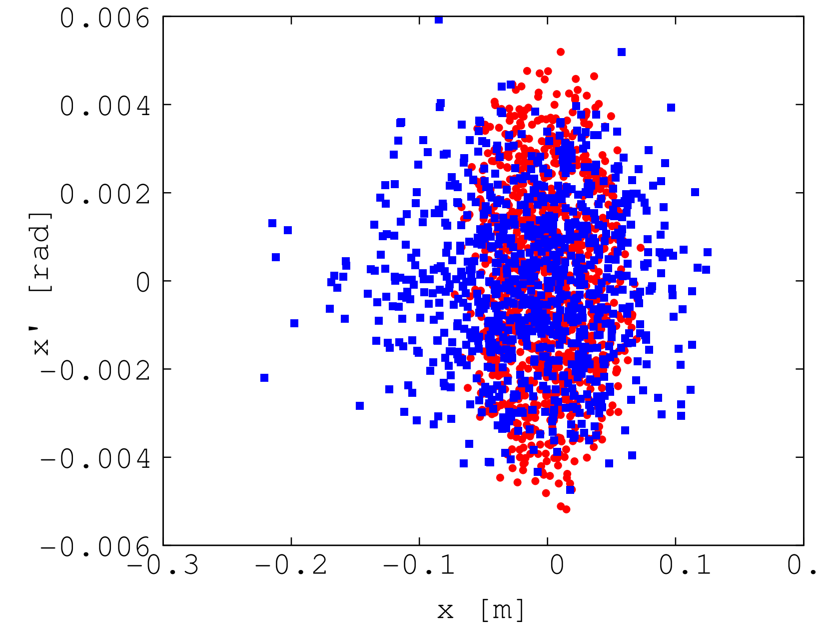
Initial phase: Red
($\varepsilon_{unnormalized}$ ~ 400π mm mrad)

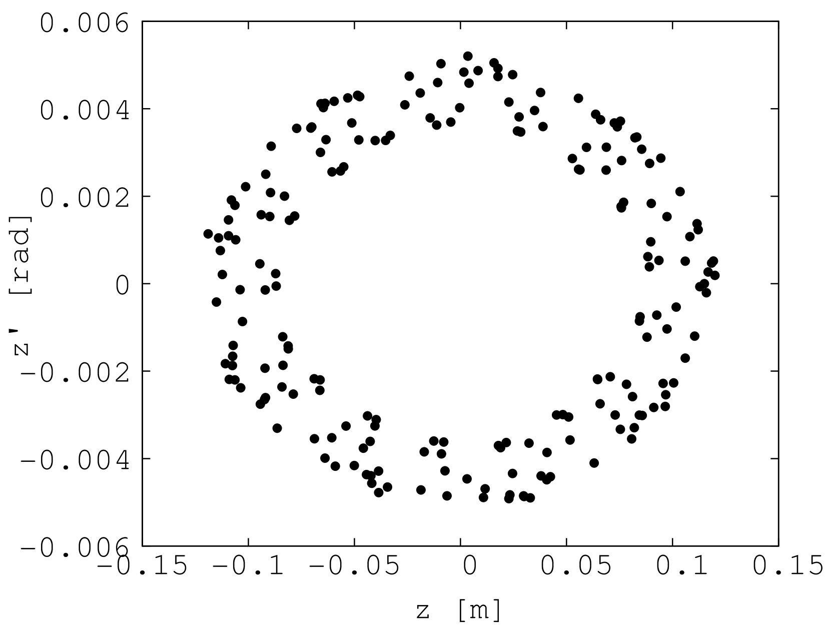
After 100 turns: Blue

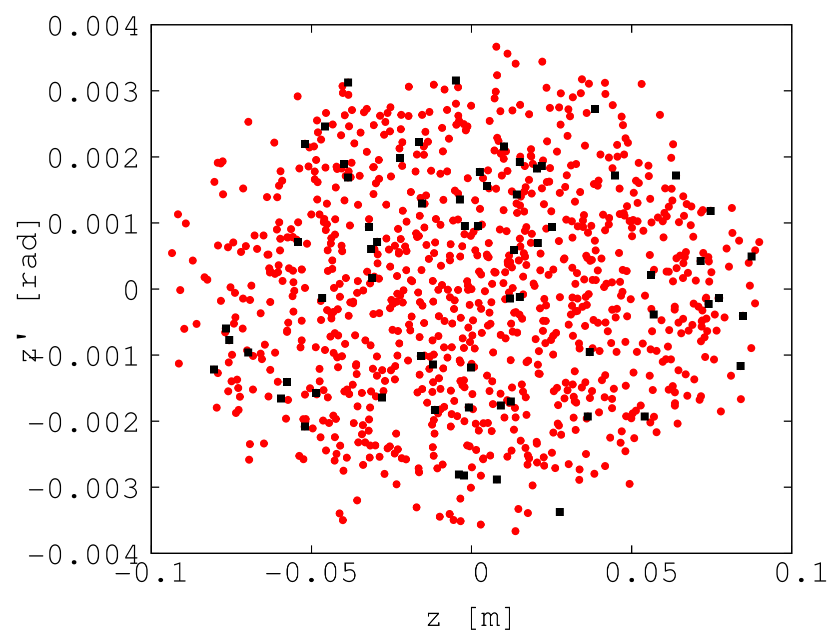




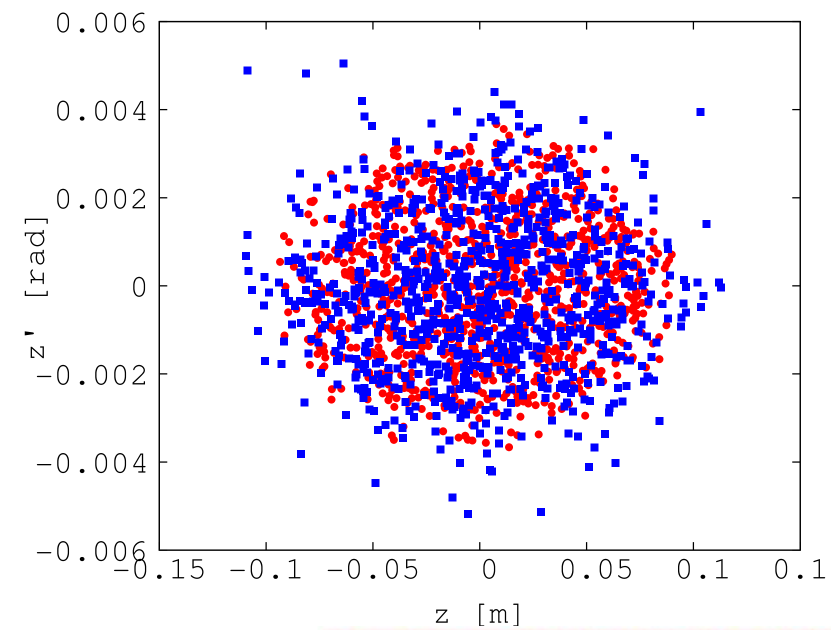
± 0.075m, ± 0.005rad





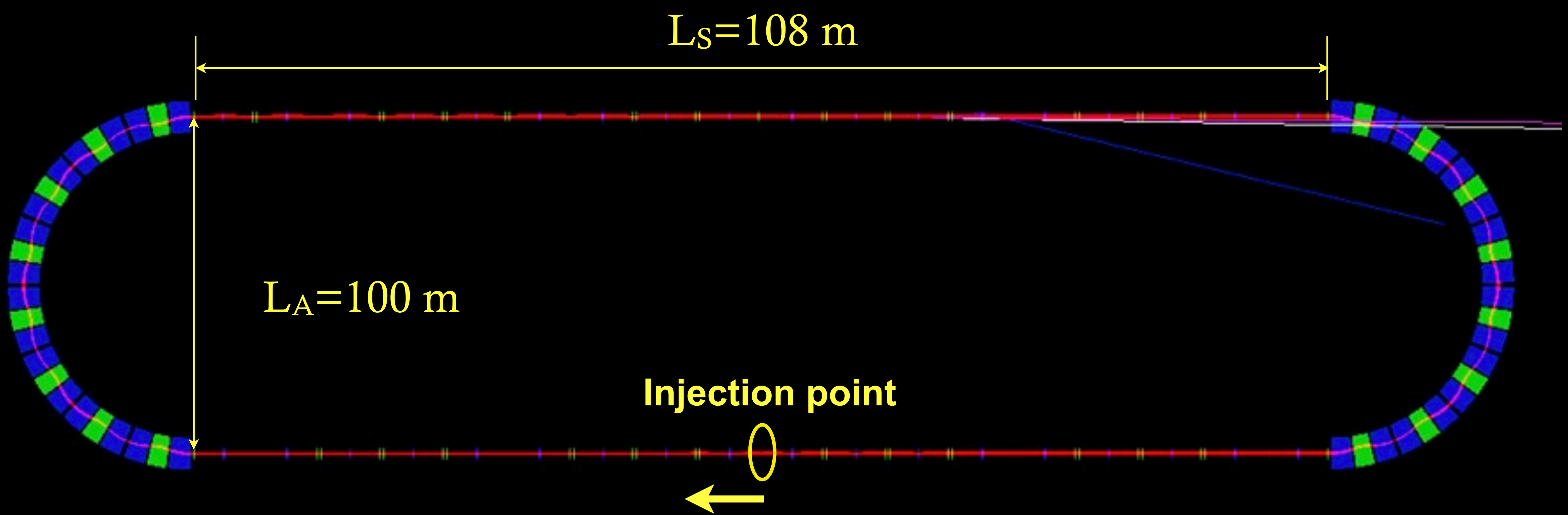


± 0.090m, ± 0.035rad



from JB. Lagrange, acc-kurri-1119-01-2011

Tracking of JB's 2GeV Ring by g4beamline

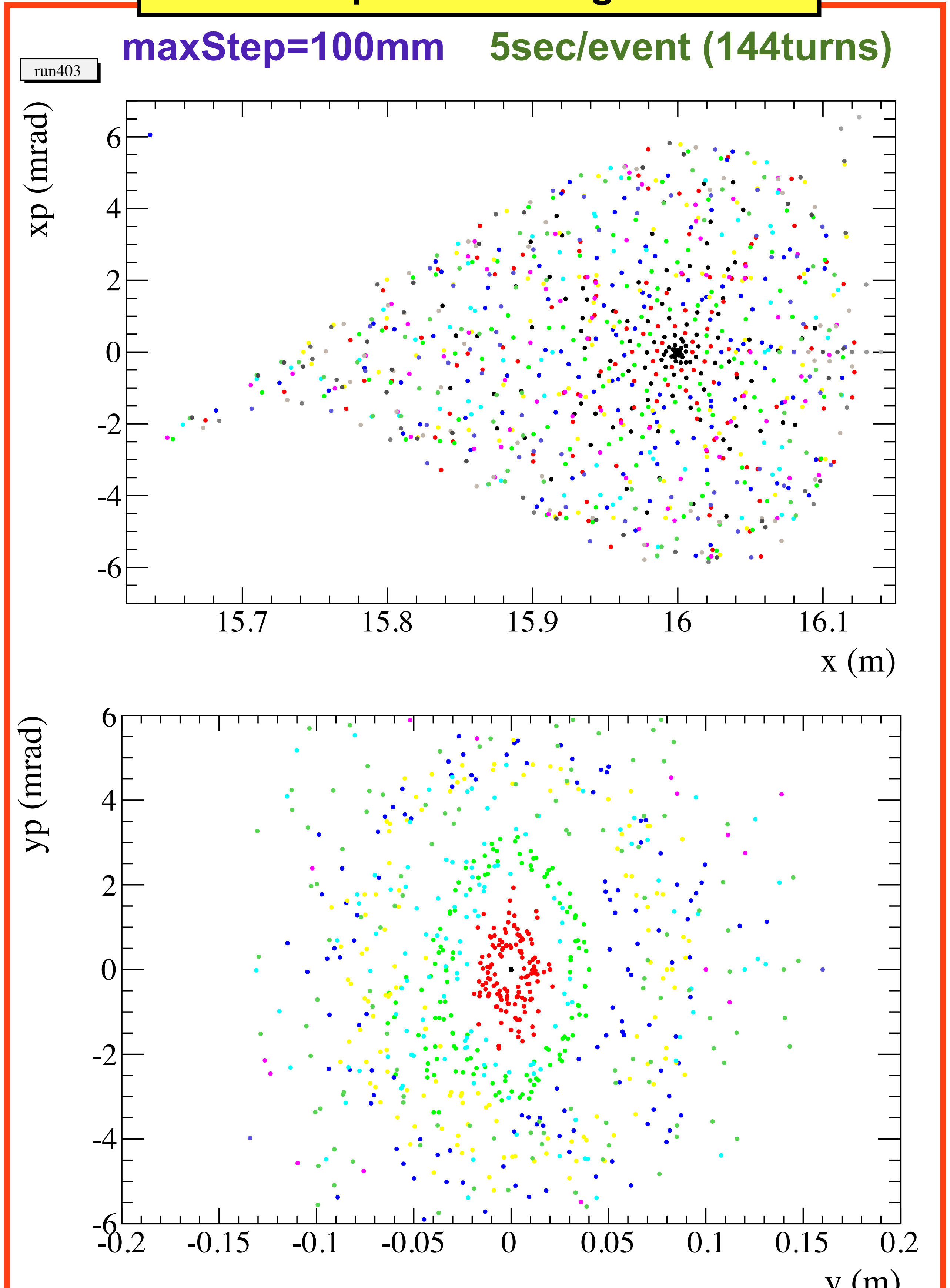


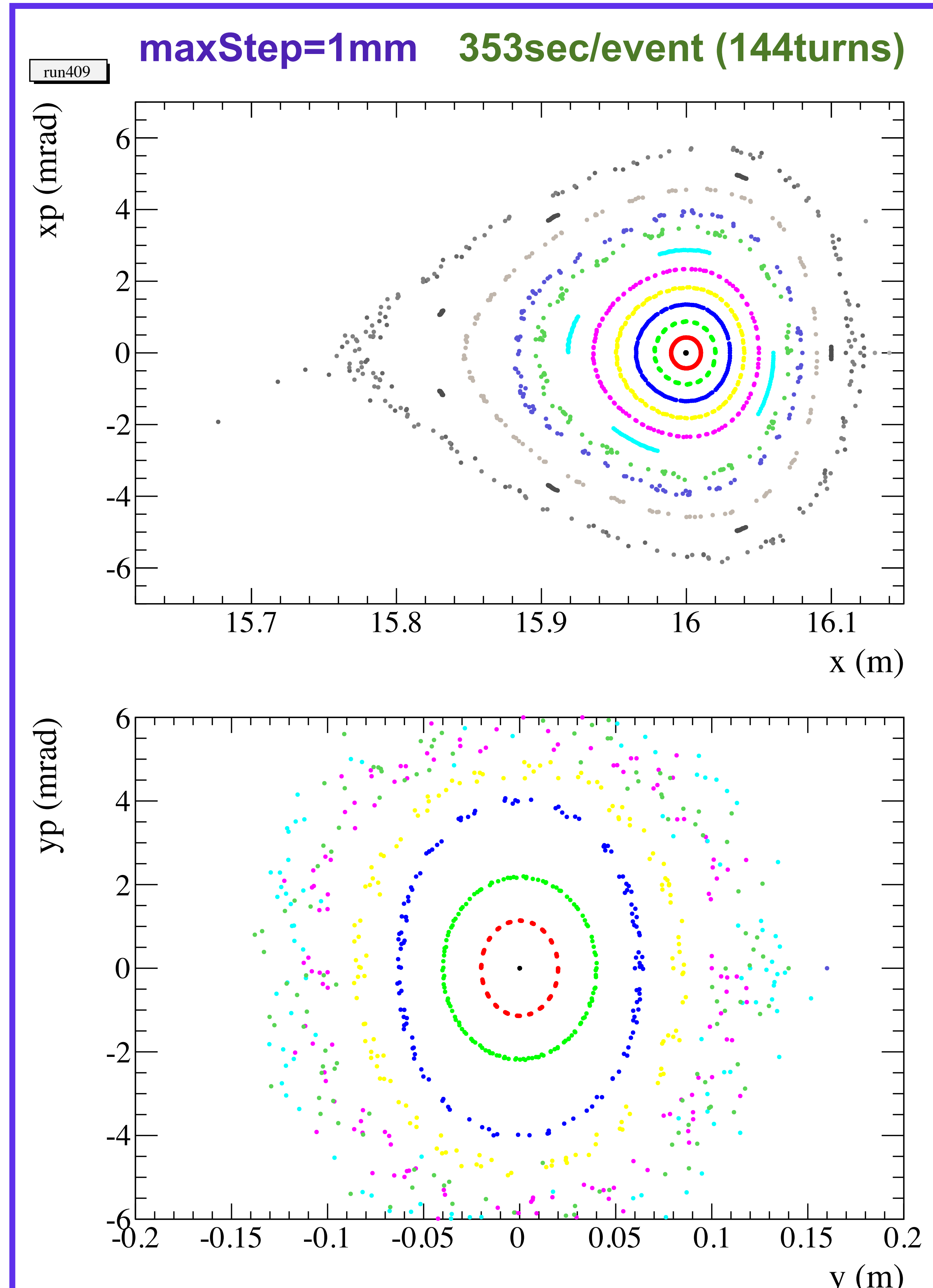
red: μ^- blue: e^- white: ν_e magenta: anti-ν_μ

Step size effects on the tracking

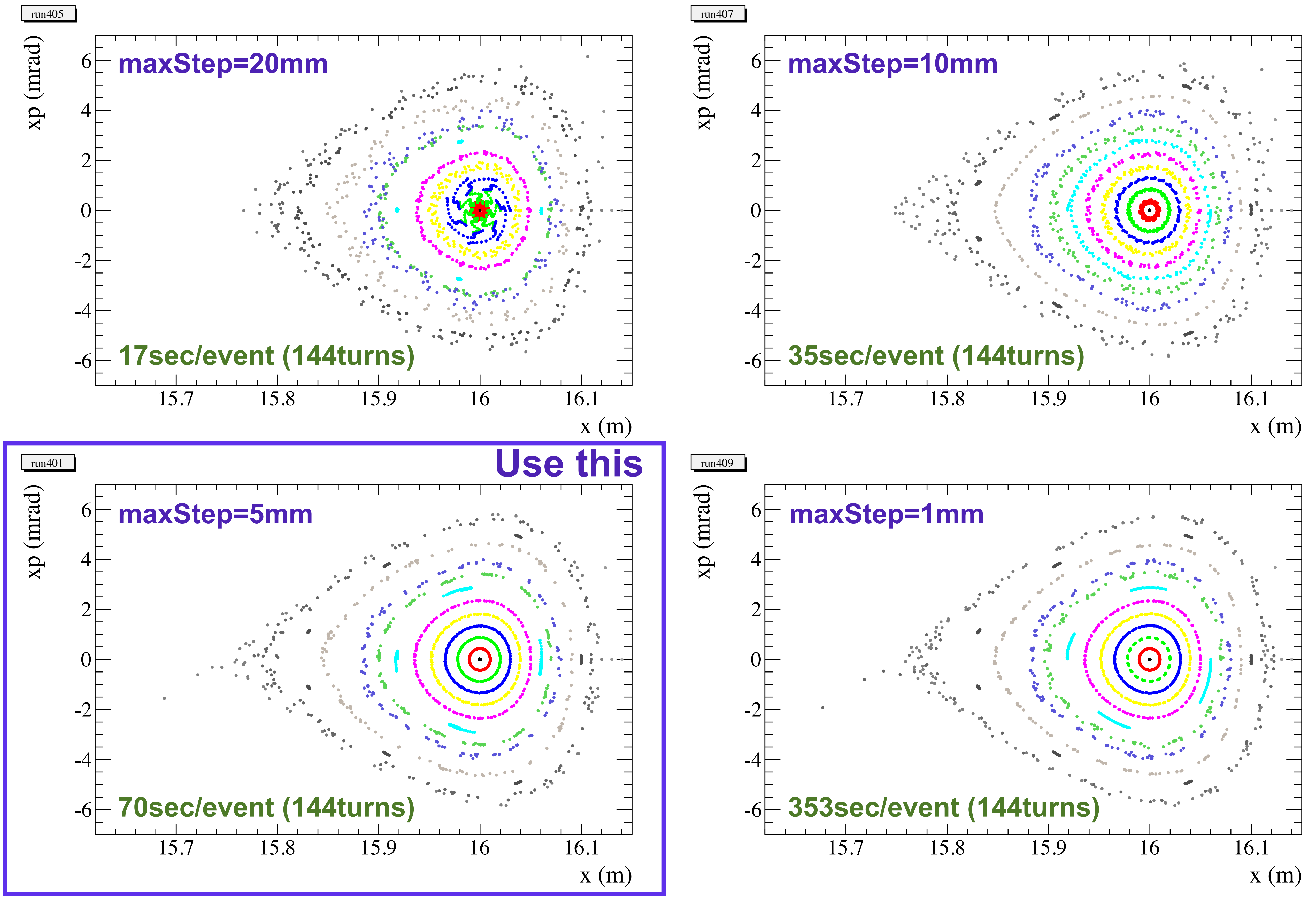
maxStep=100mm(default) vs 1mm

Default step size of the g4beamline

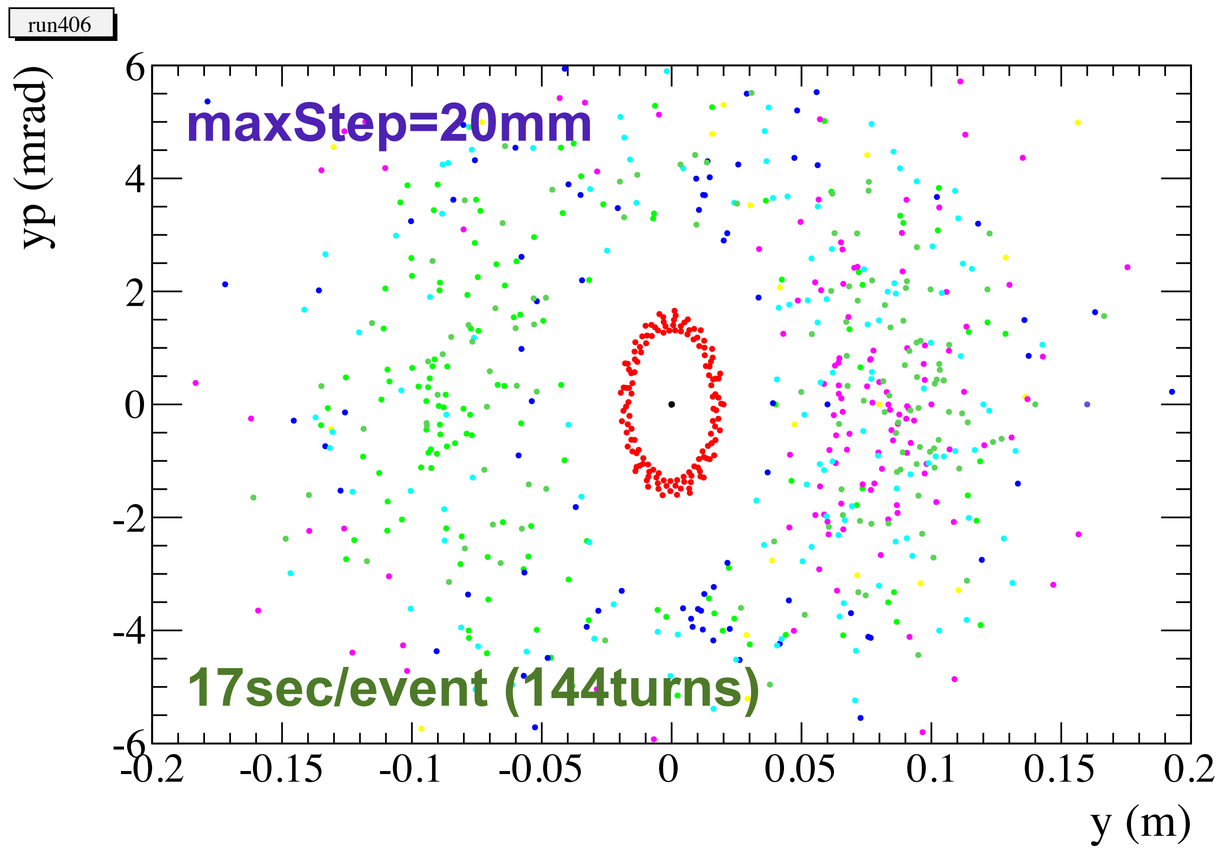


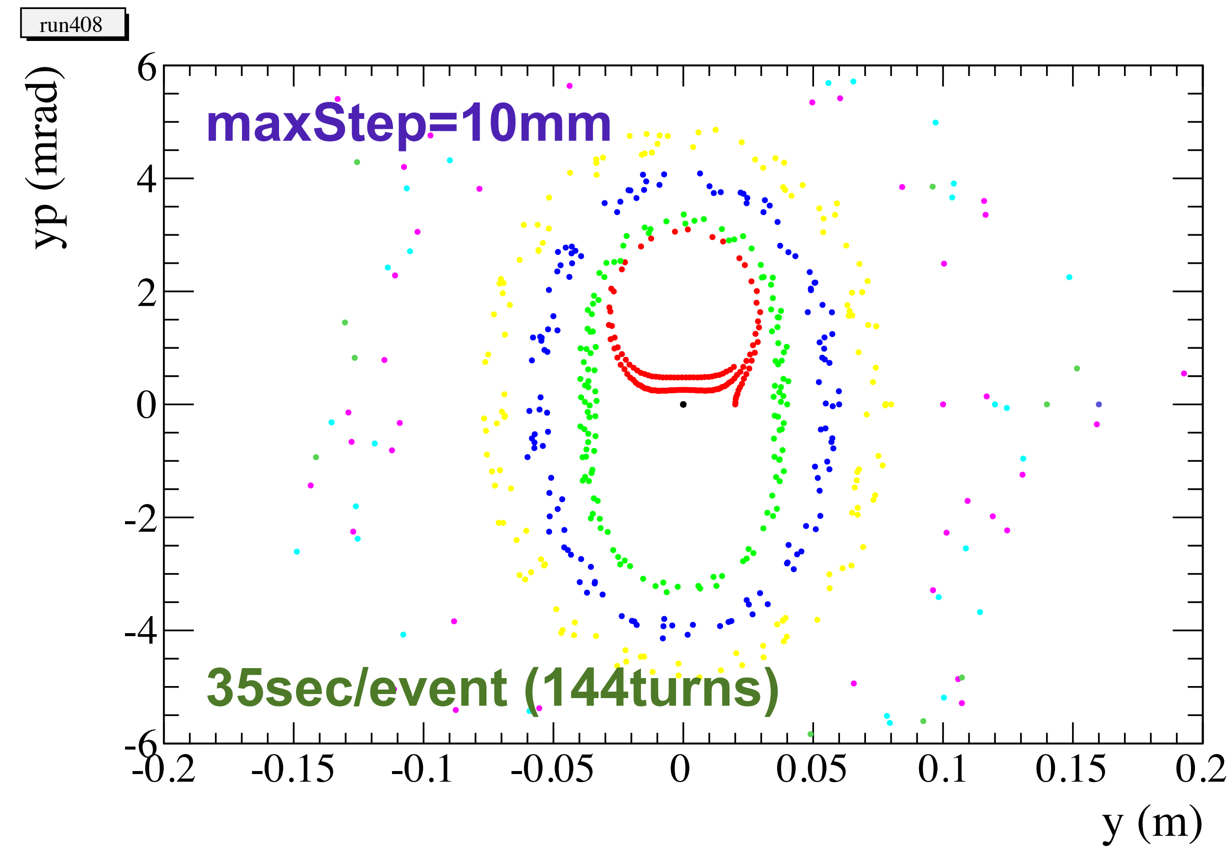


Horizontal

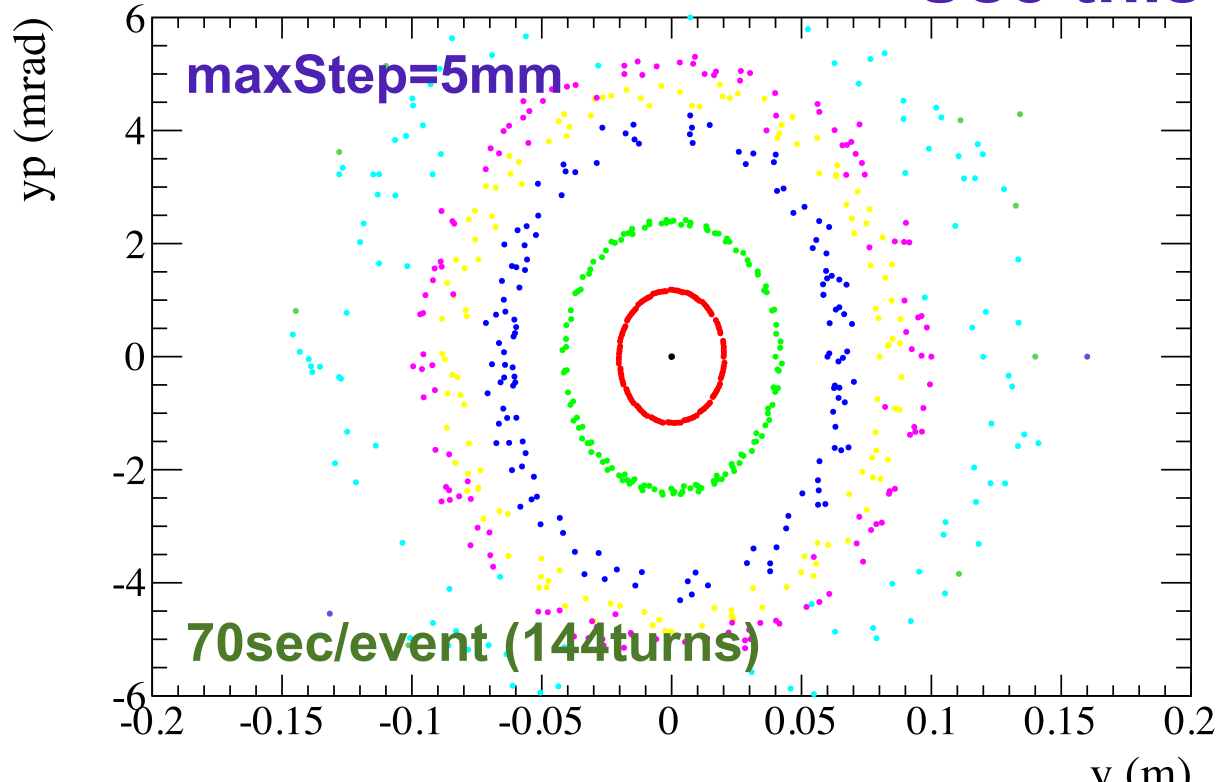

run405
maxStep=20mm
17sec/event (144turns)
run407
maxStep=10mm
35sec/event (144turns)
Use this
run401
maxStep=5mm
70sec/event (144turns)
run409
maxStep=1mm
353sec/event (144turns)
xp (mrad)
x (m)
6
4
2
0
-2
-4
-6
15.7
15.8
15.9
16
16.1

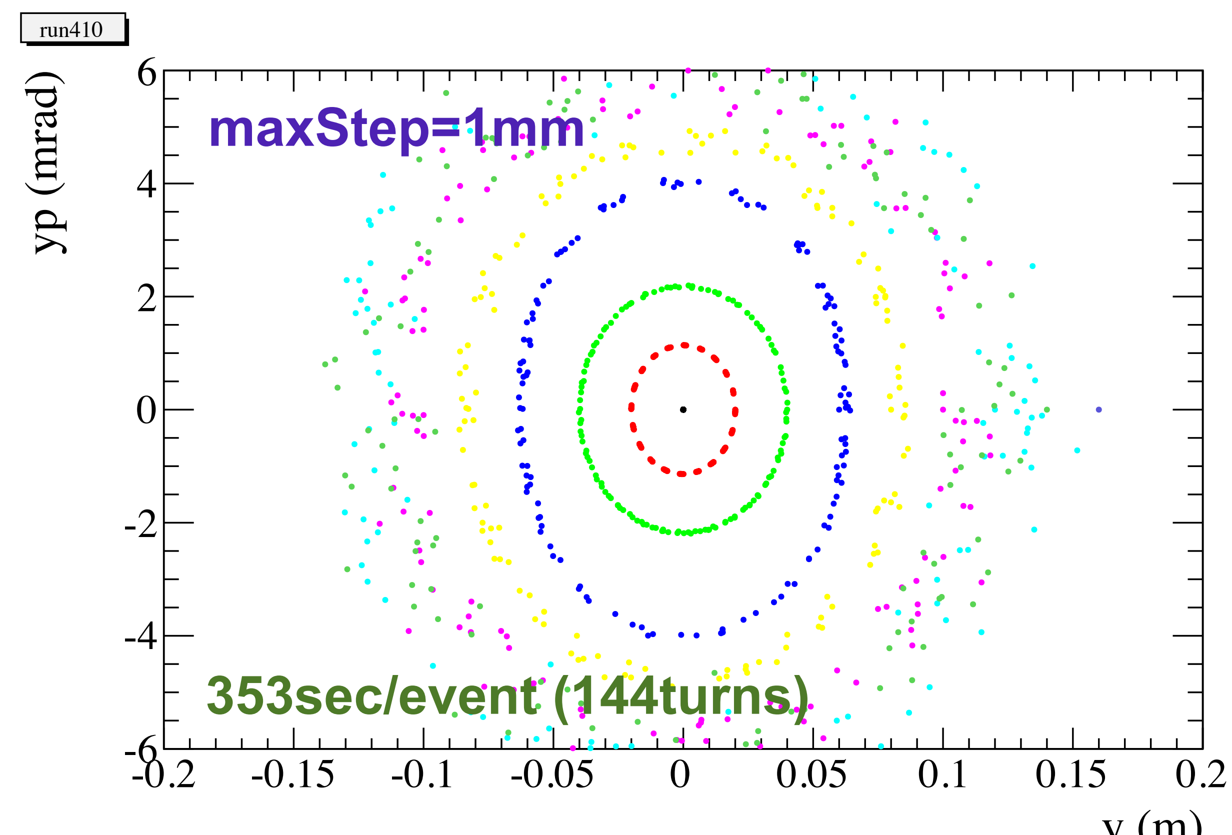
Vertical





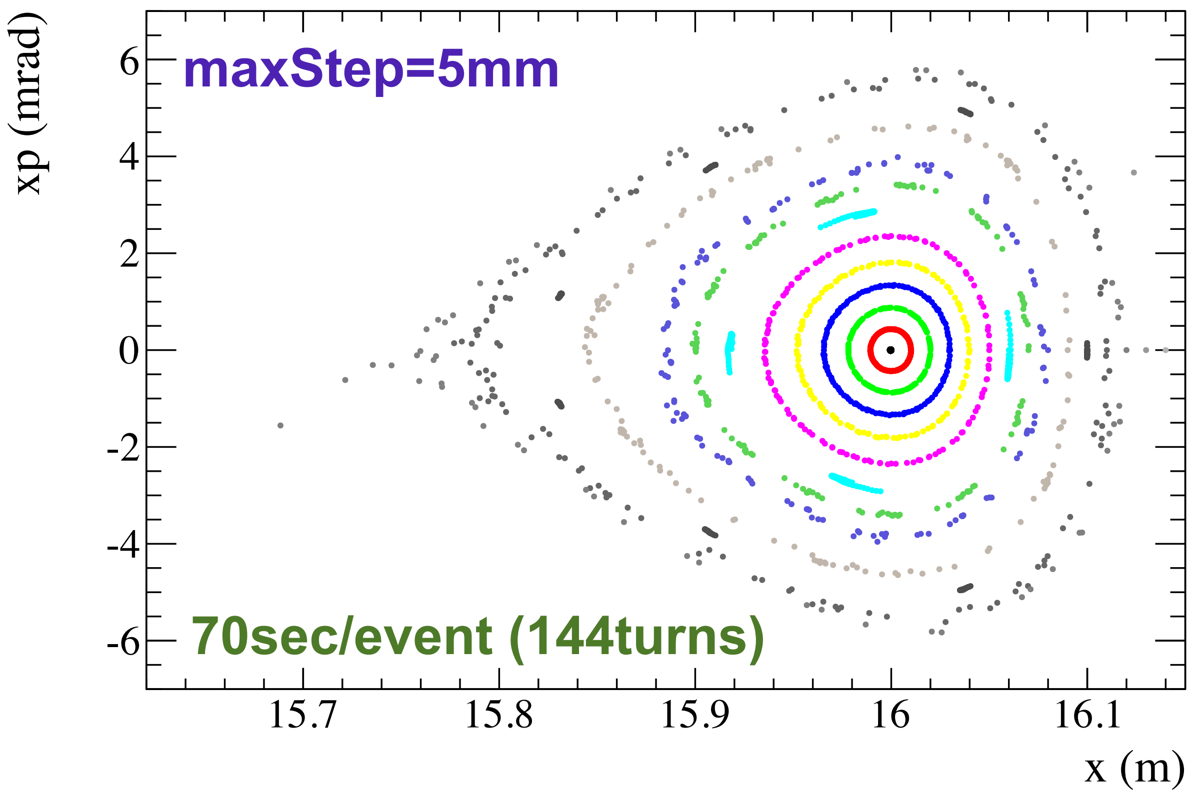
Use this

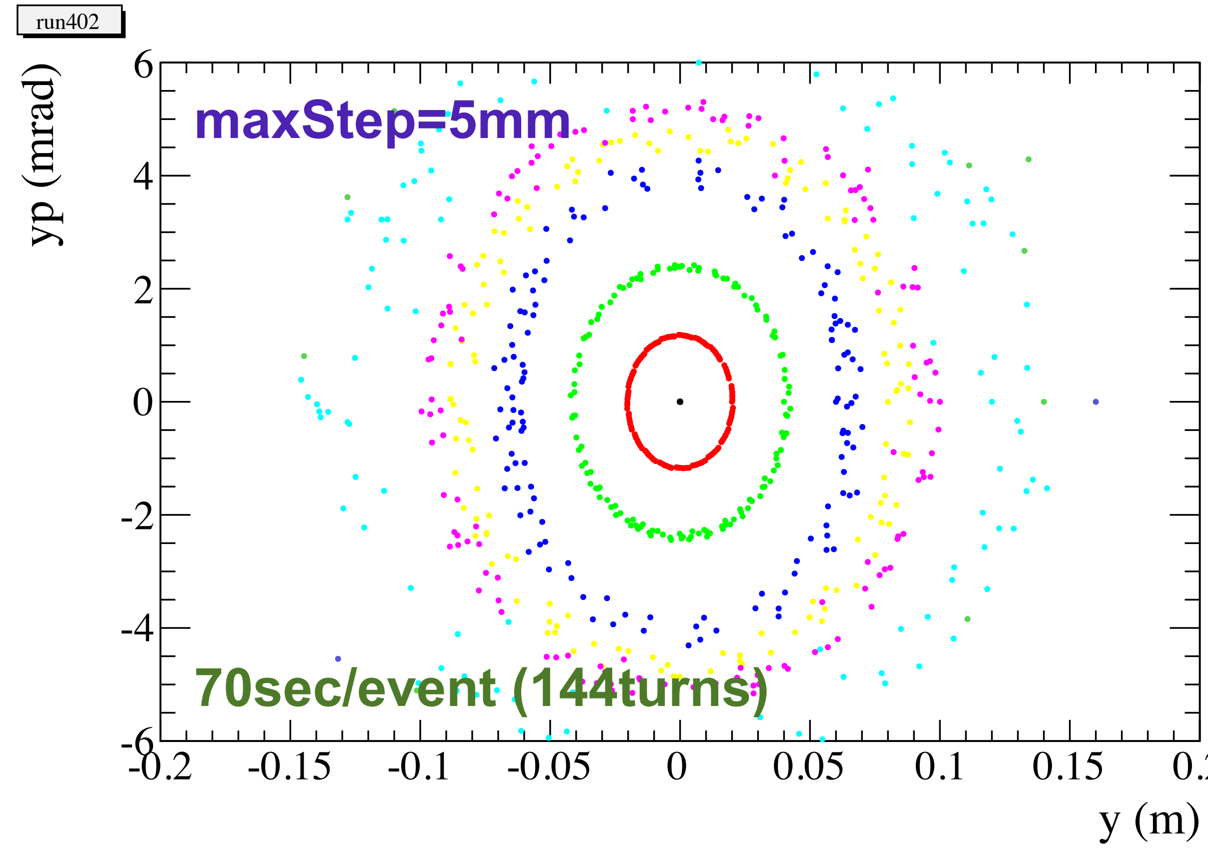




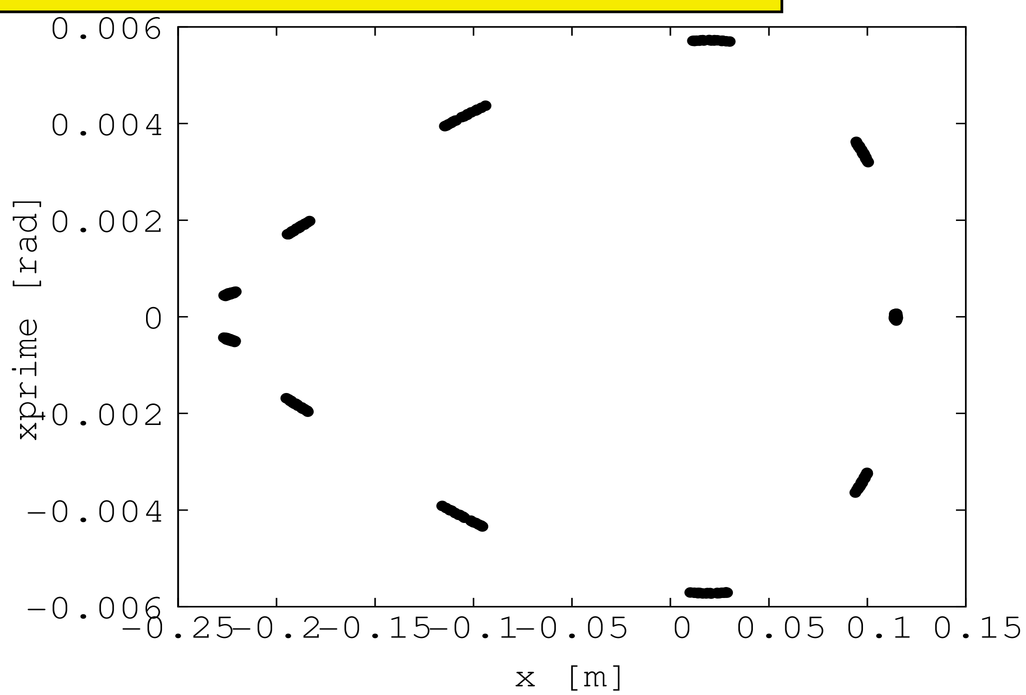
Comparison with JB's tracking results

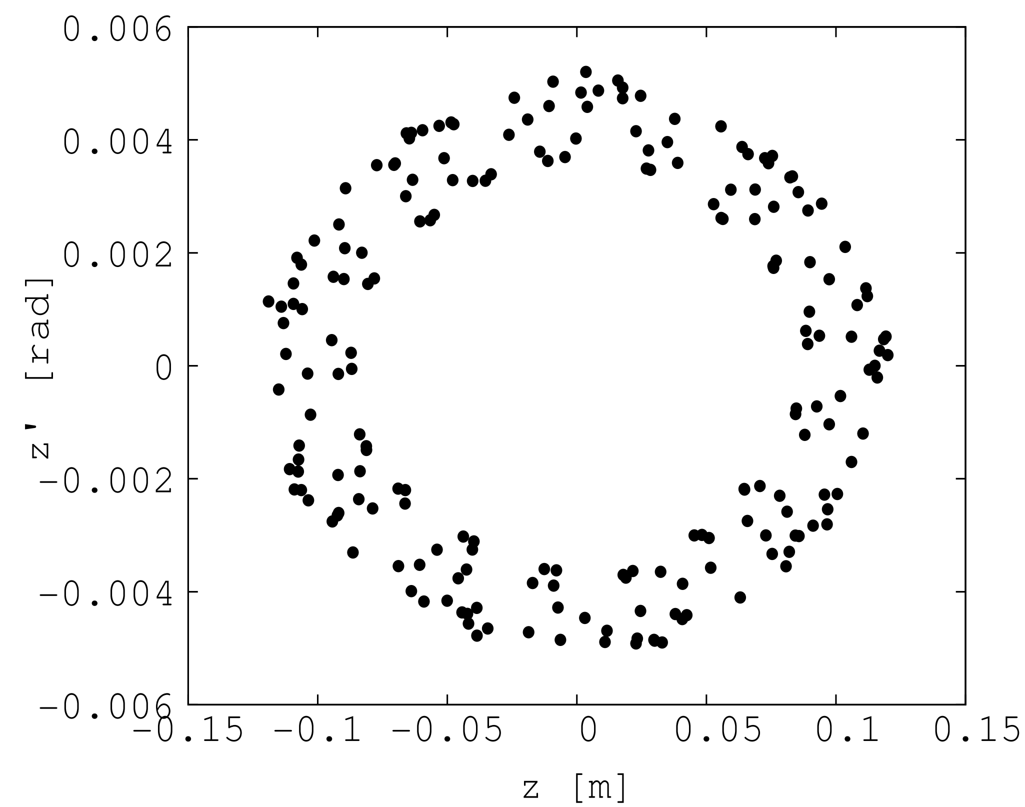
g4beamline



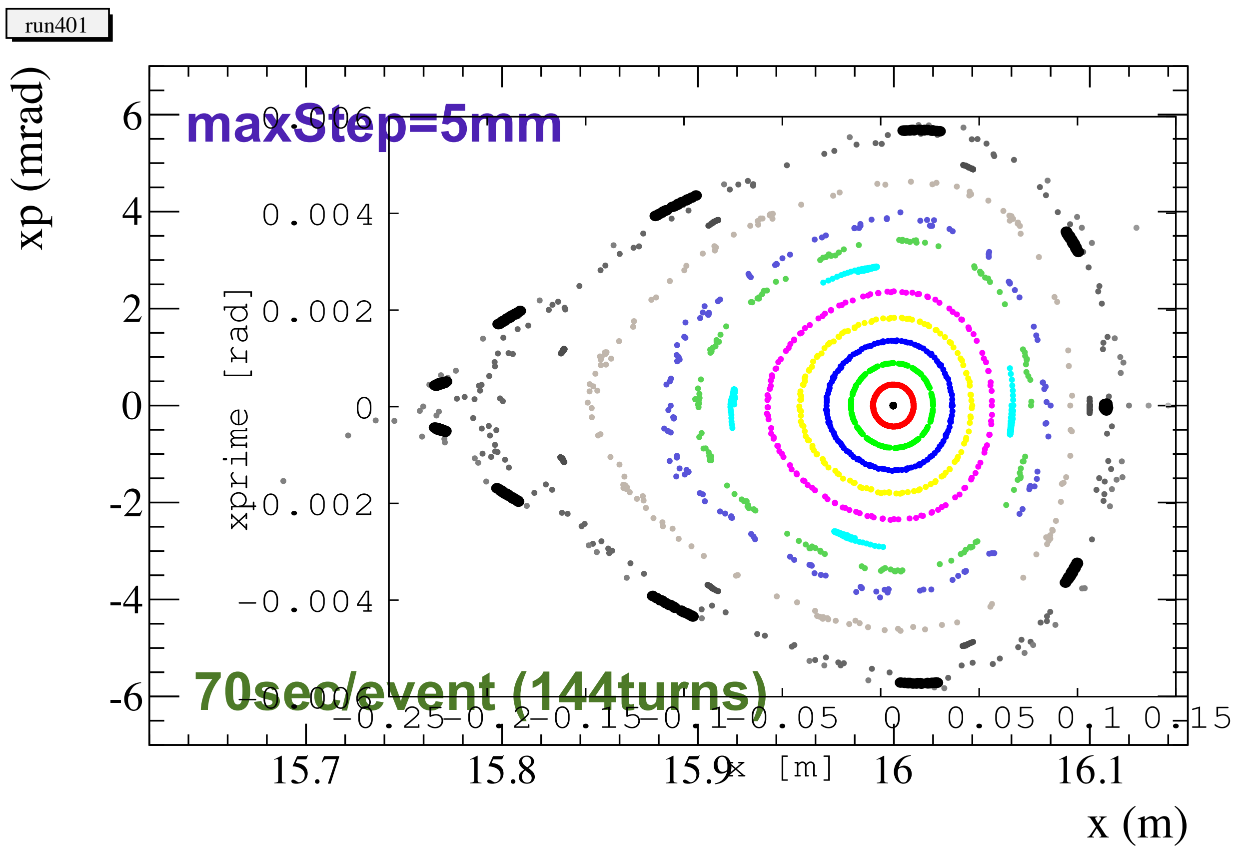


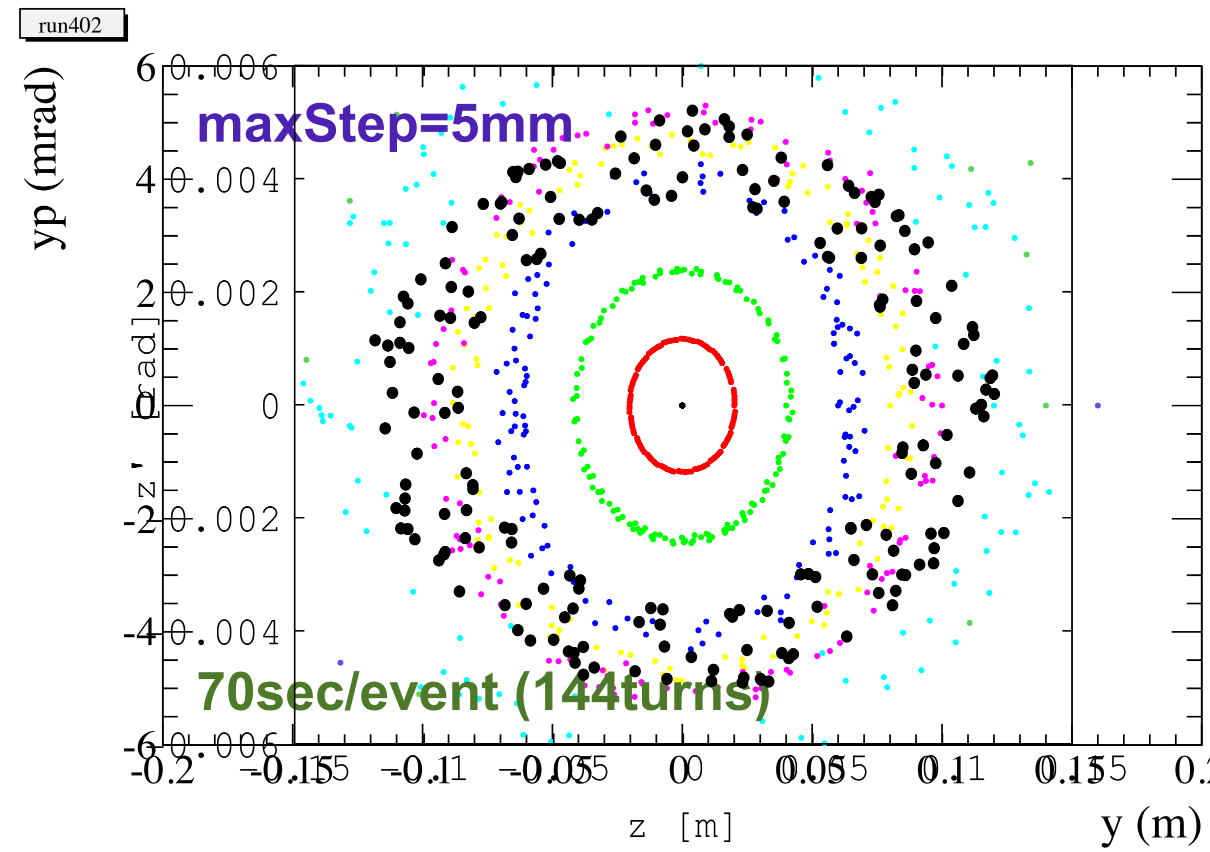
JB's original tracking code





Comparison b/w JB’s results

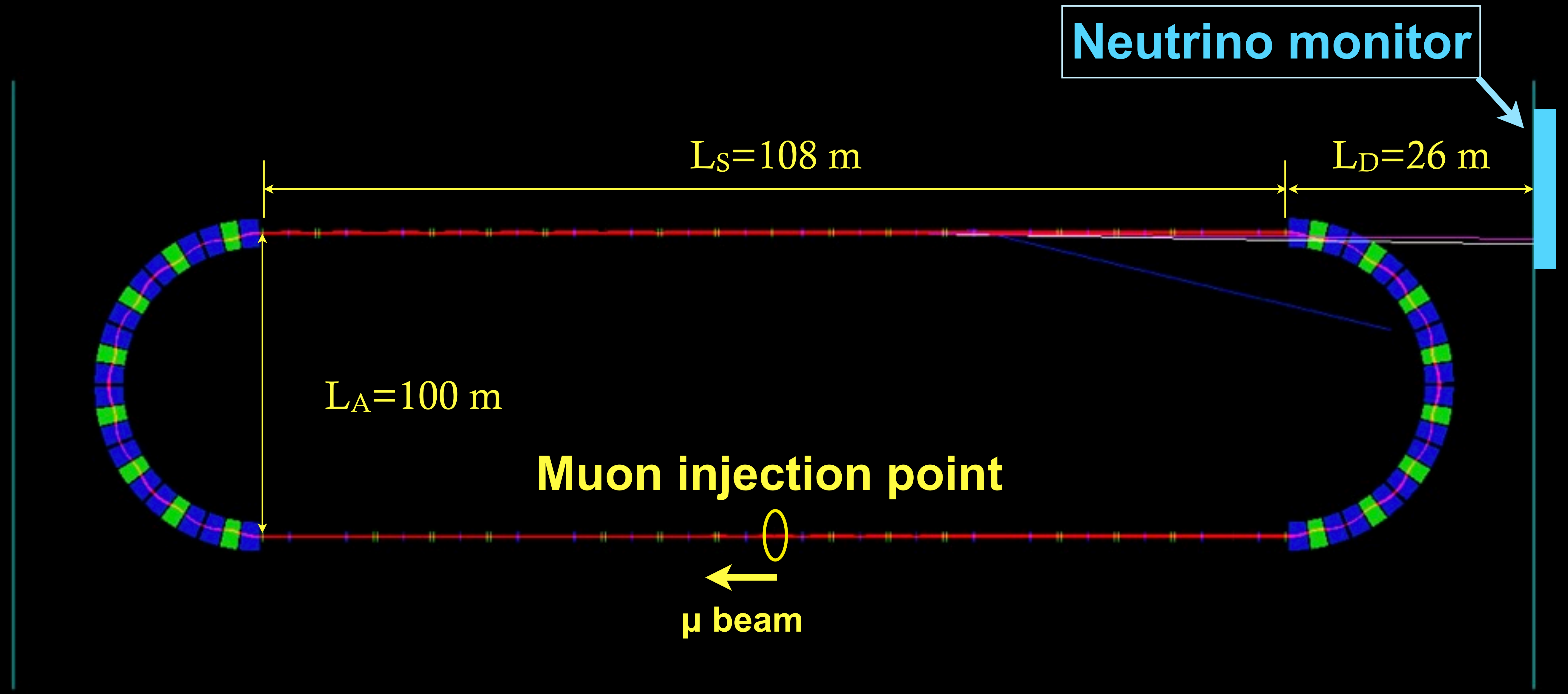




- The tracking results of g4beamline are in very good agreement with the JB’s result.
- I use maxstep=5mm in the following tracking.
  - note: The grid size of magnetic field maps must be also enough small to get reasonable accuracy.

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

Neutrino production with JB's 2GeV Ring by g4beamline

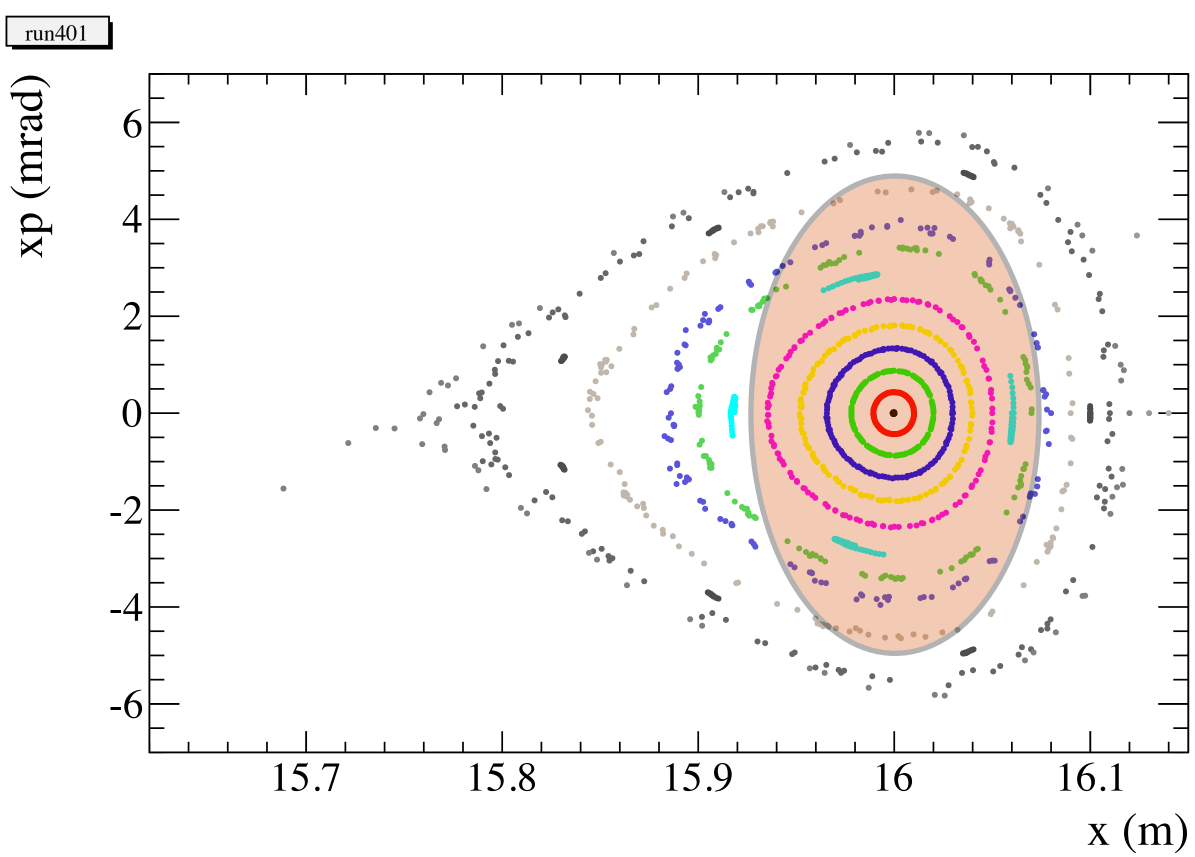


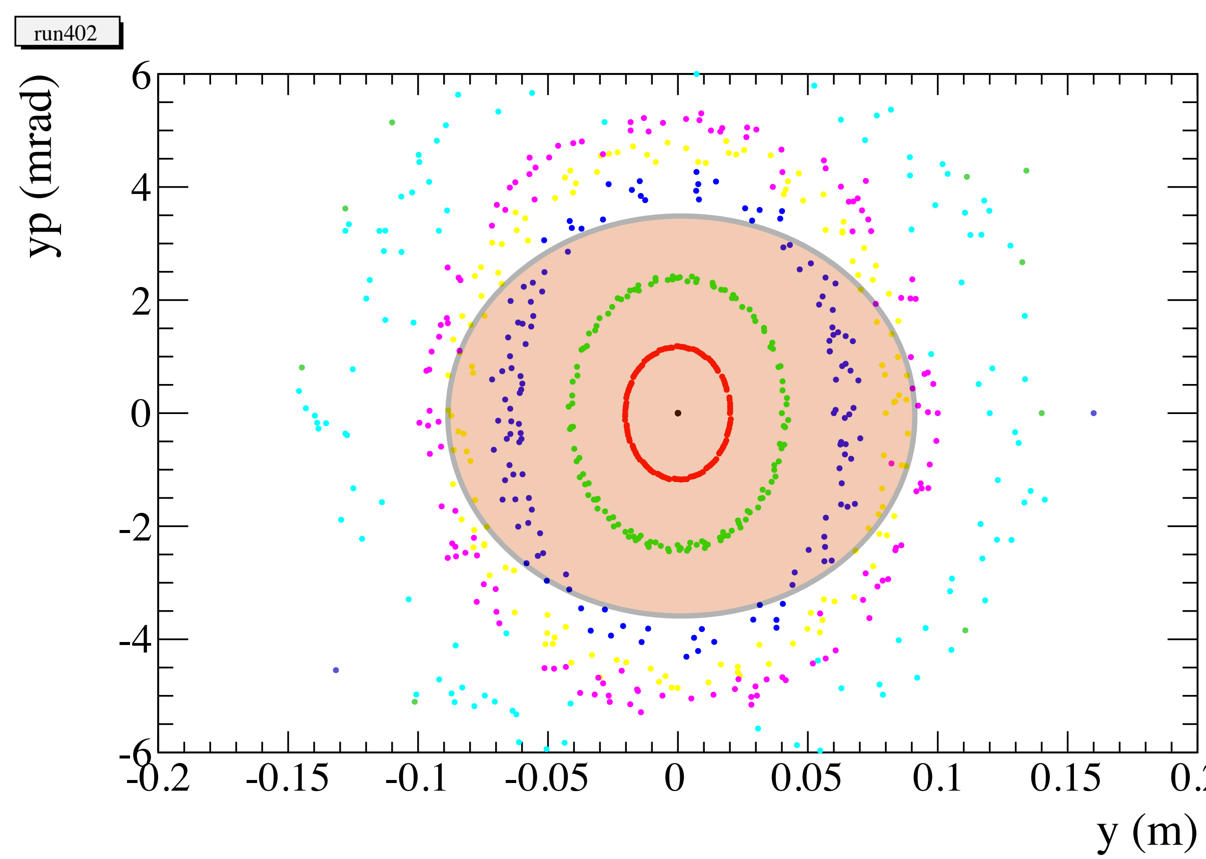
red: μ^- blue: e^- white: ν_e magenta: anti-ν_μ

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

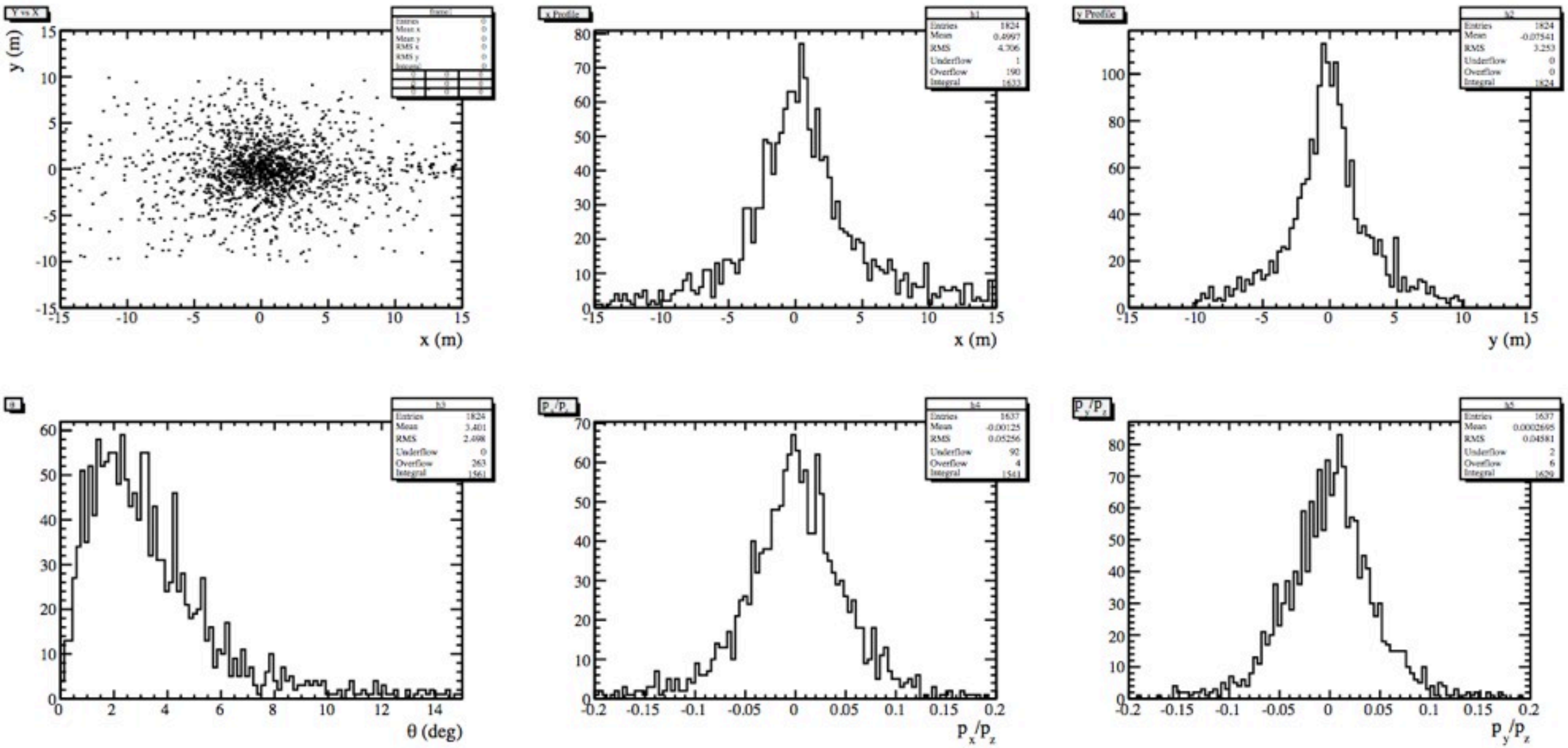
Beam size for E_{μ}=2GeV±16% is decided from the dispersion, but no dispersion matching was made in this simulation.





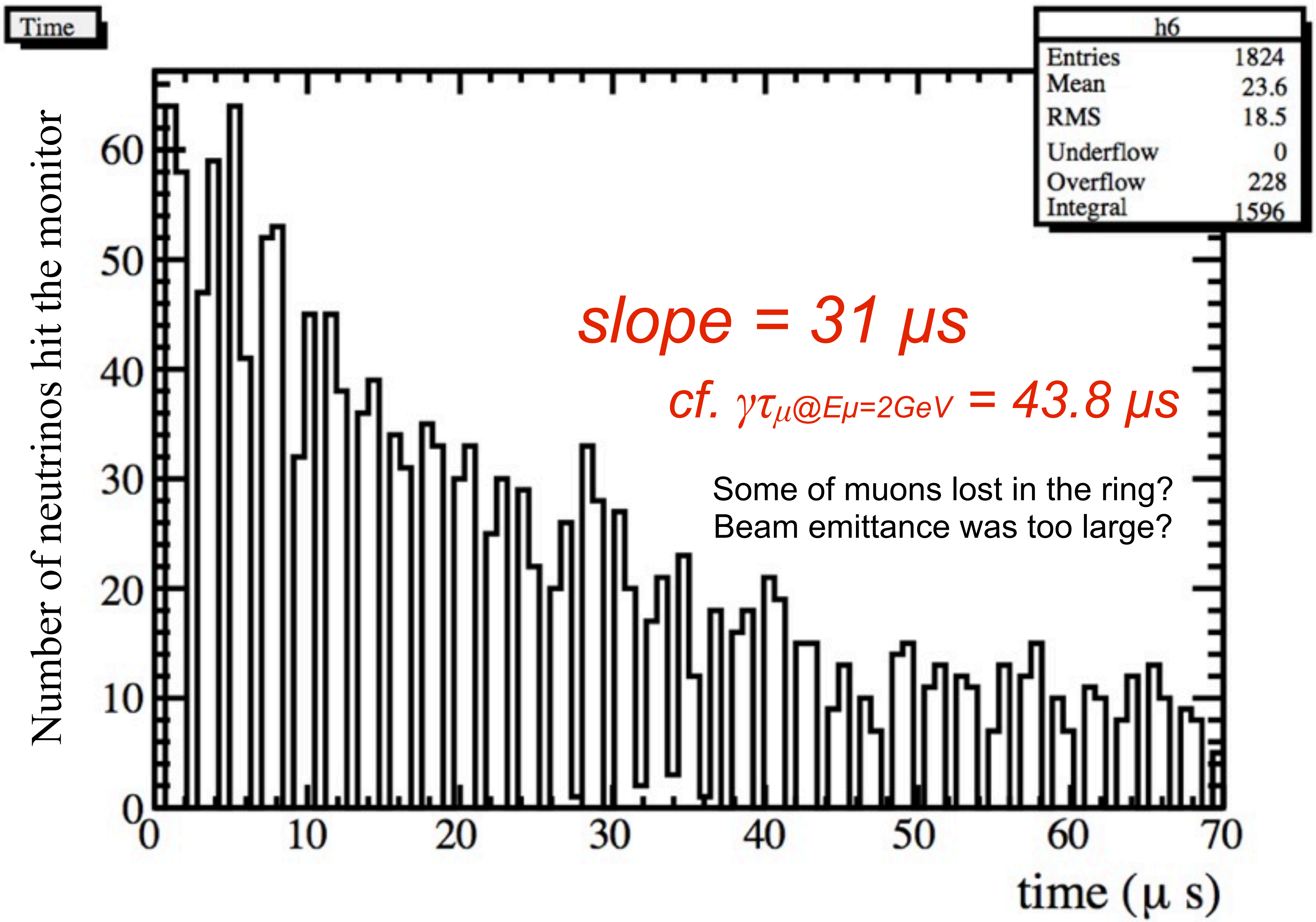
Neutrino beam at the monitor : $\mathbf{E_{\mu}=2.0GeV \pm 0\%}$

L_S=108 m, L_D=26 m



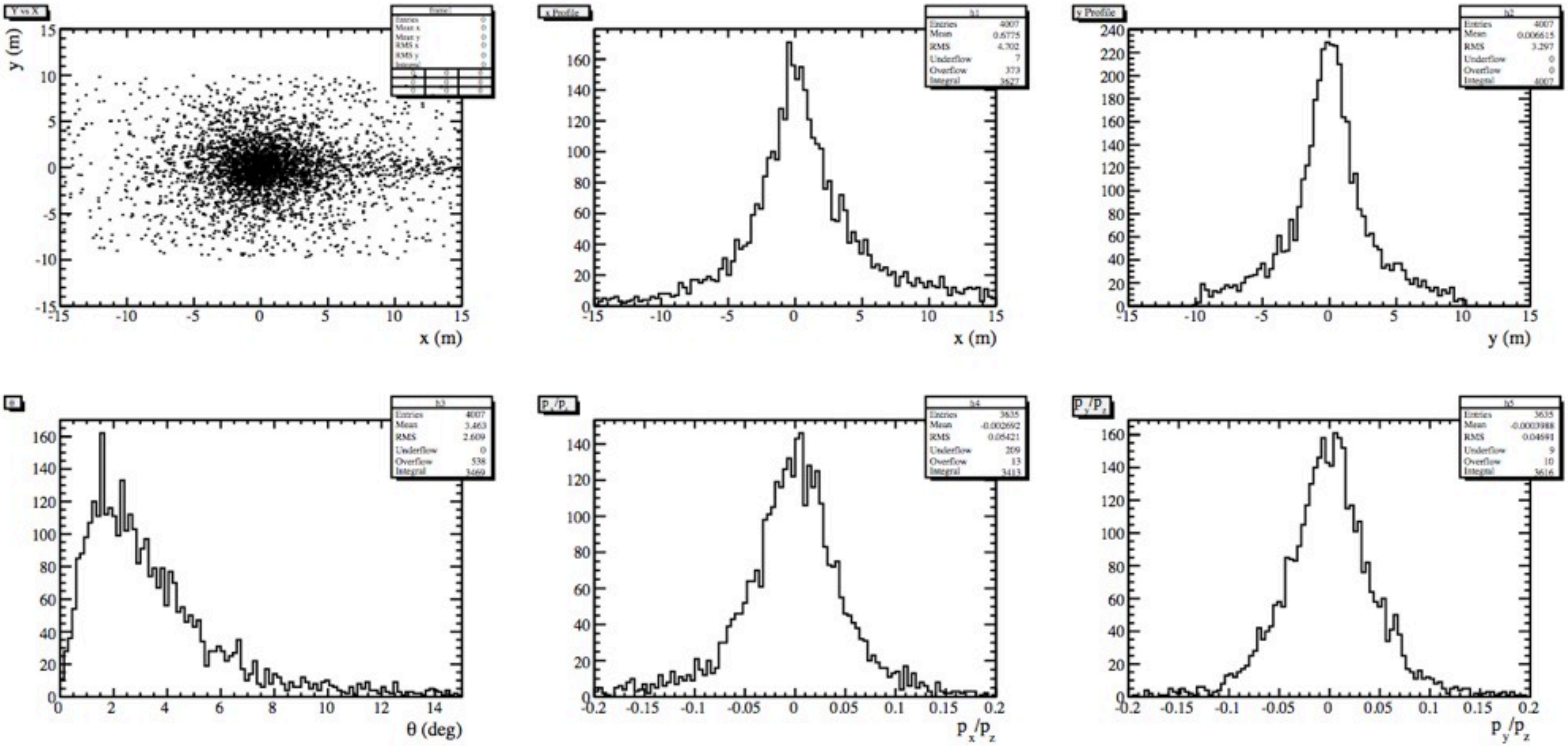
13 sec/event on icore7

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



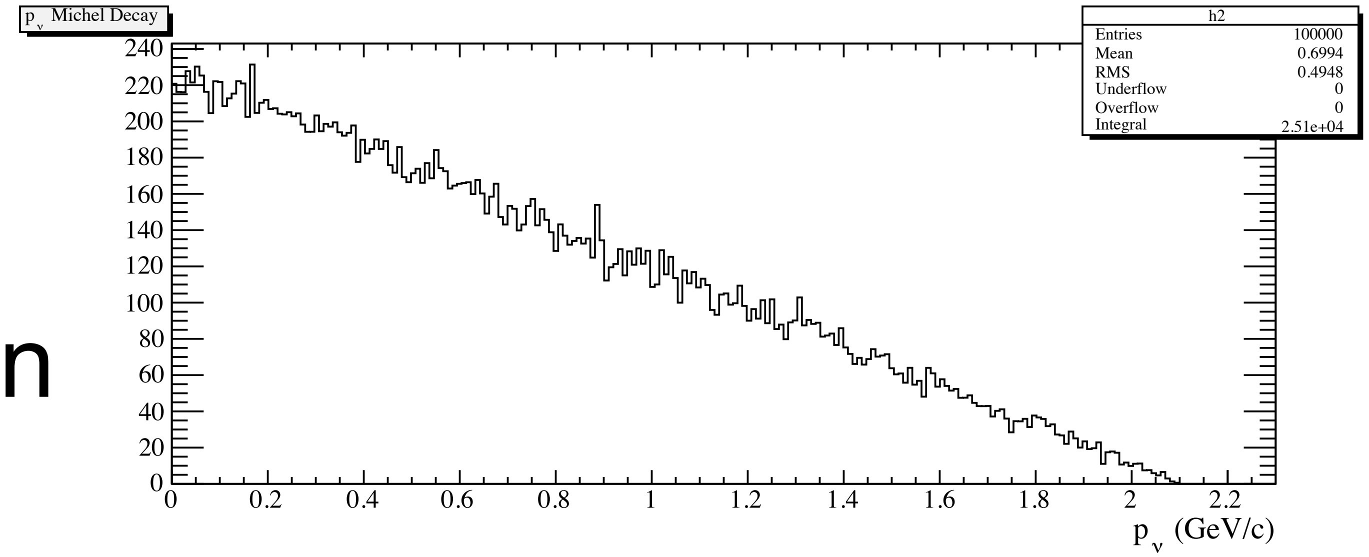
Neutrino beam at the monitor : $\mathbf{E_\mu}$=2.0GeV ± 16%

L_S=108 m, L_D=26 m

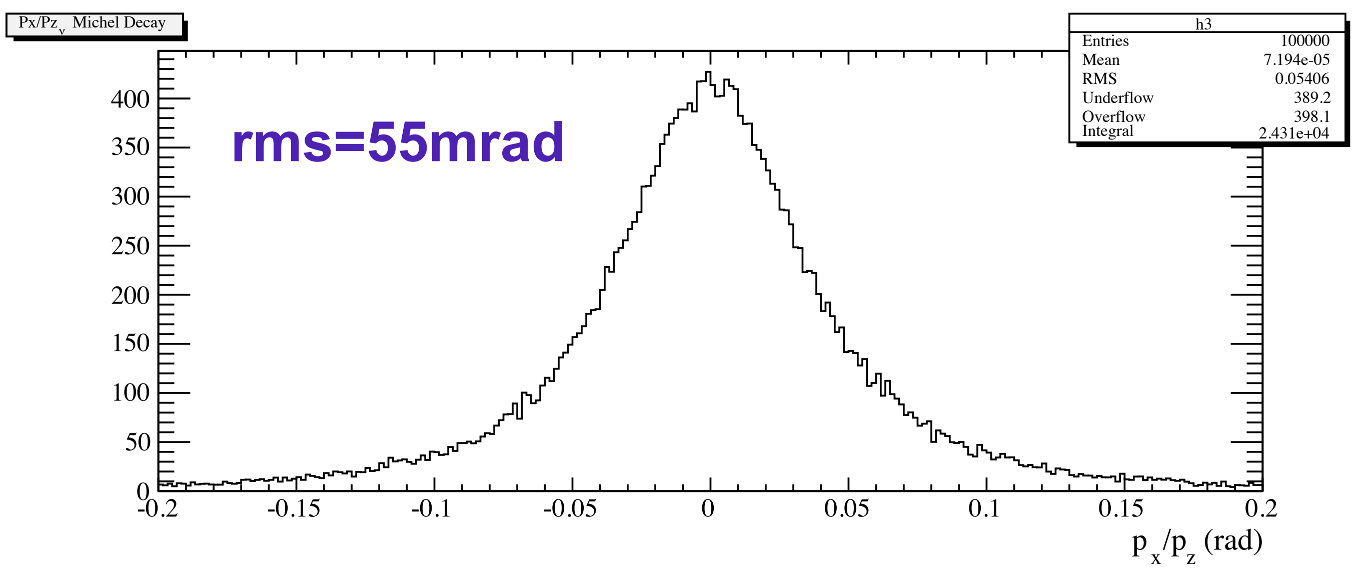


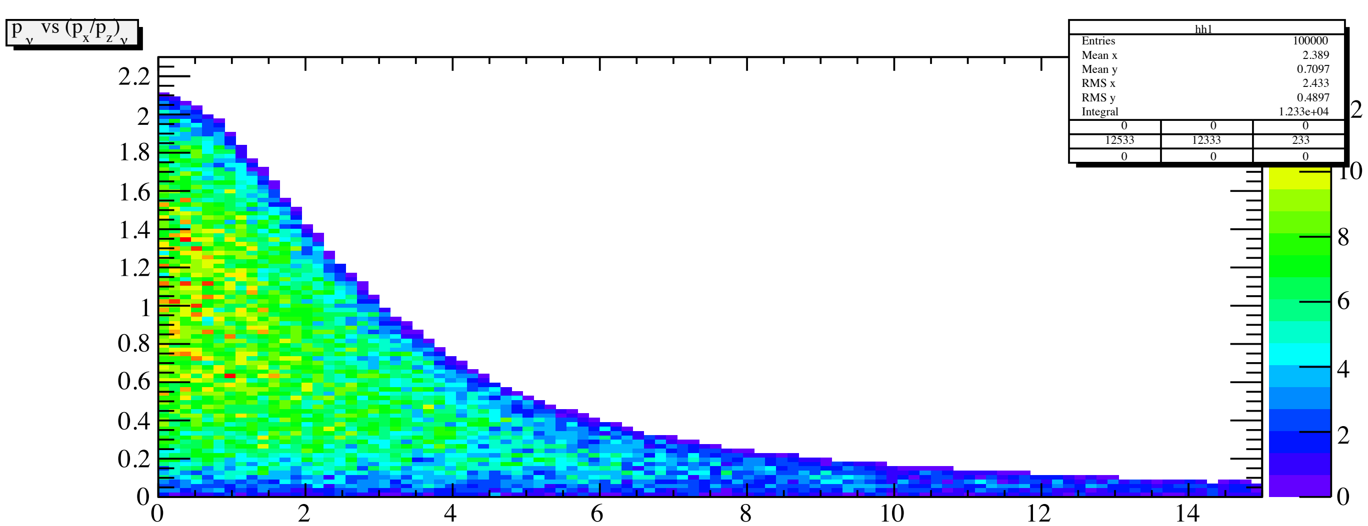
Neutrino production from muon decay in flight

E_μ=2.0GeV
* Energy conservation
* Momentum conservation
* Lorenz boost

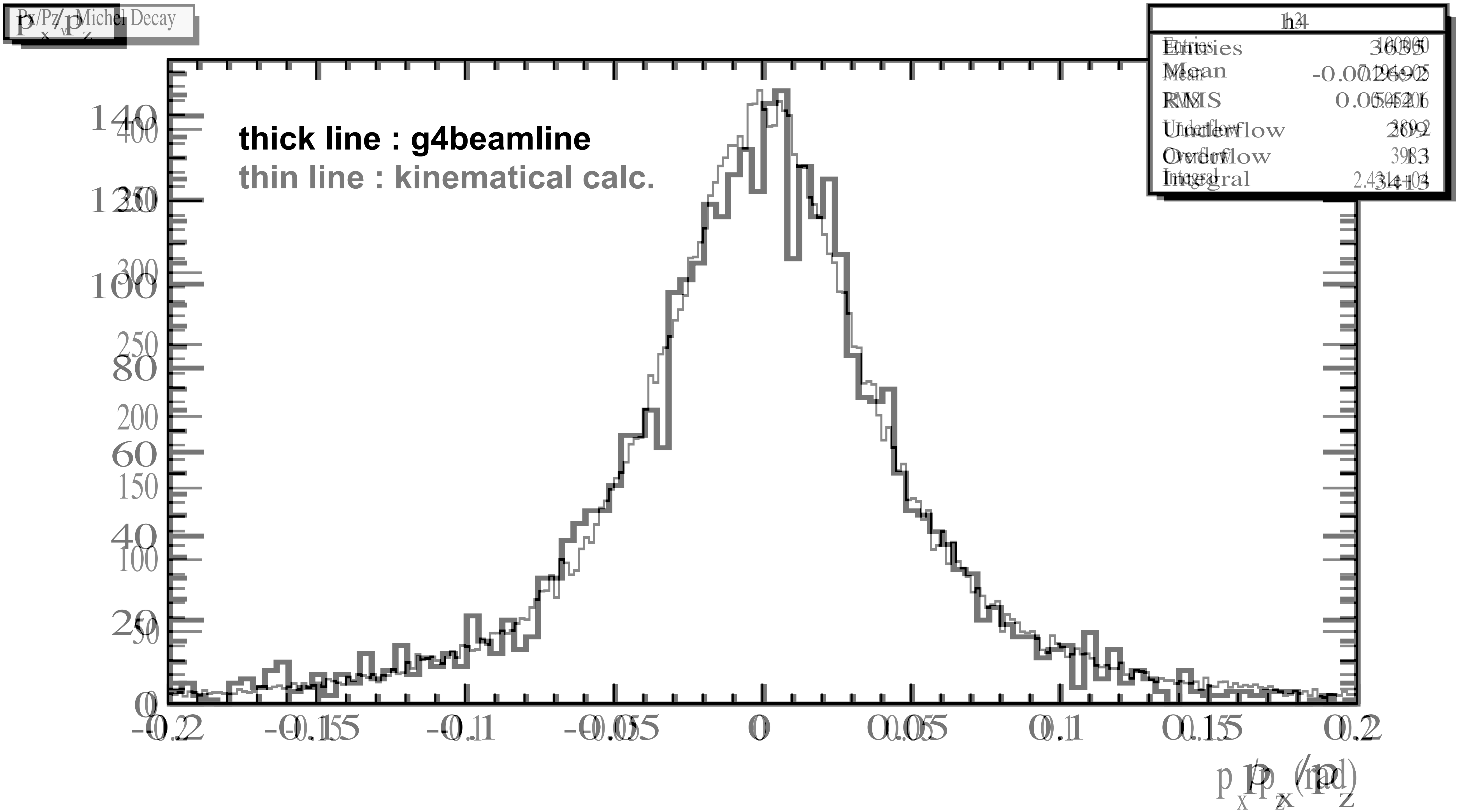


Compare this with the tracking results.

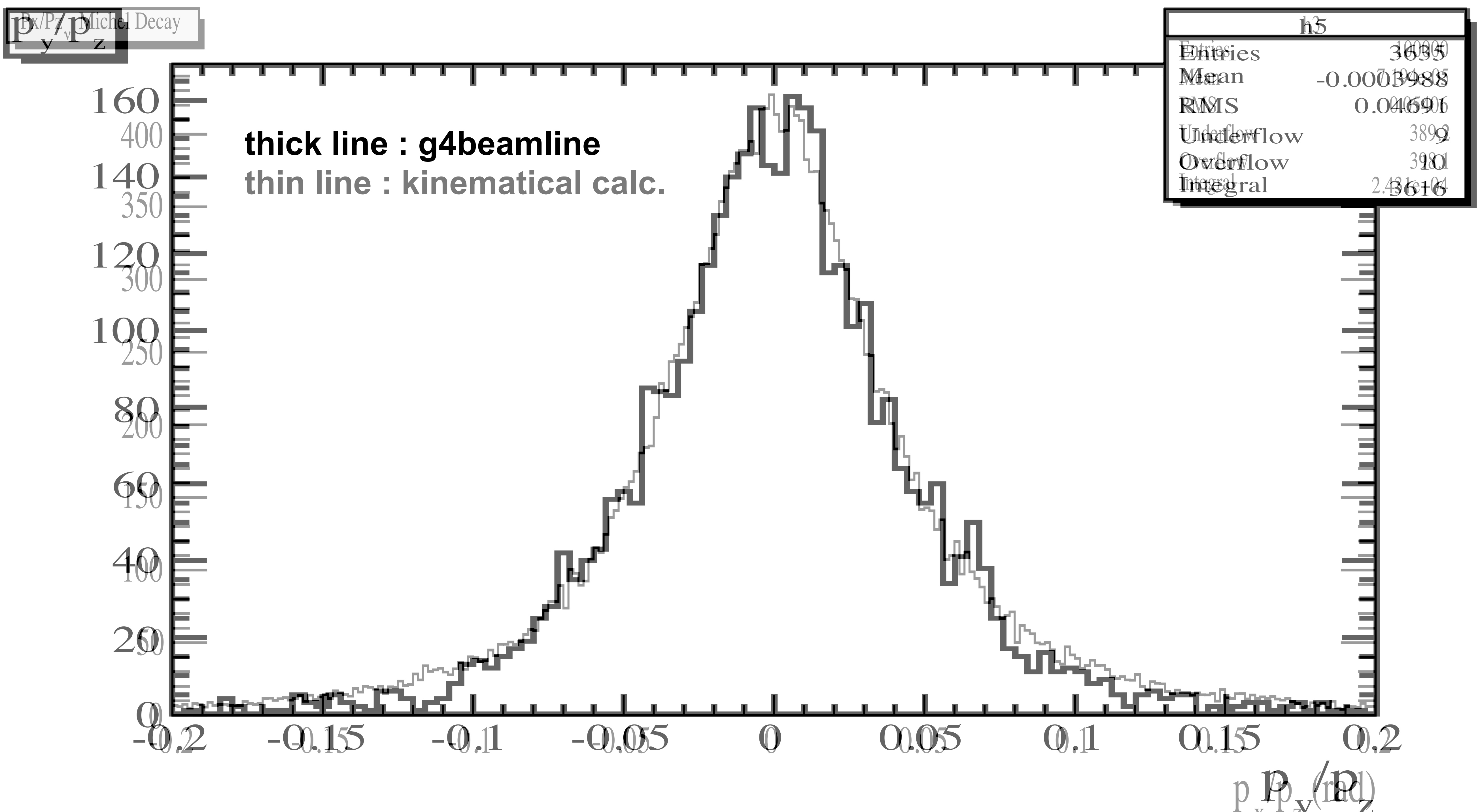




Beam gradient X, p_x/p_z: run412: E_μ=2.0GeV ± 16%



Beam gradient Y, p_y/p_z: run412: E_μ=2.0GeV ± 16%



Effect of serpentine orbit at the straight section is negligible in the gradient of neutrino beam, as expected.

Conclusions

- **An advanced scaling Racetrack-FFAG ring has been designed by JB. Lagrange as a 2GeV muon decay ring for the VLENF.**
  - Energy acceptance is 2GeV±16%,
  - L_S=108m, L_A=100m
- **The first g4beamline tracking in the Racetrack-FFAG ring has been performed. With maxStep=5mm and fine grid magnetic field maps, the tracking results show very good agreement with results from JB's tracking code.**
- **Neutrino production has been also tried with g4beamline. Profiles of the neutrino beam at L_D=26m was shown. They have very good performance.**
- **This Racetrack-FFAG ring has enough space to handle the injection of muon beam. Optics studies are needed for that.**