Studies on charge selection at MOMENT

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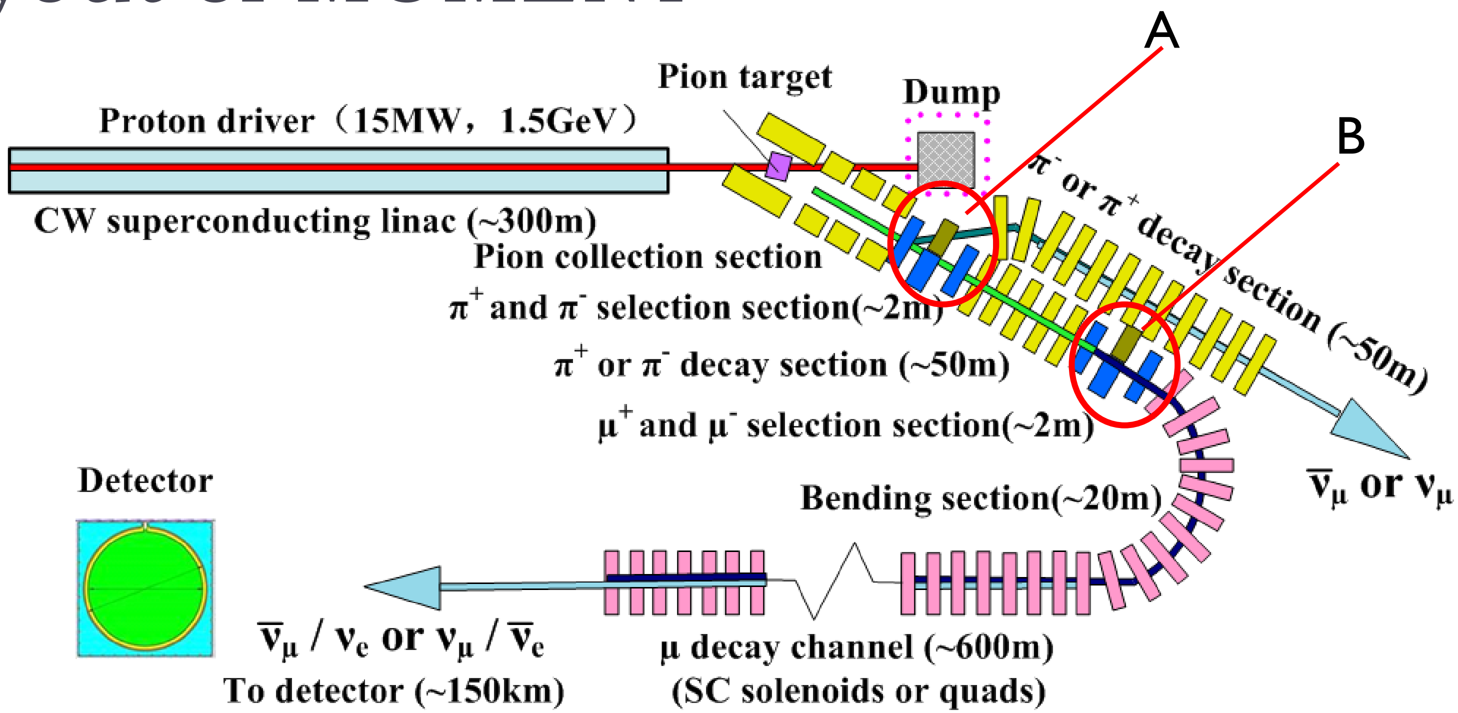
Outline

- Necessity for charge selection at MOMENT
- Charge selection by dipole chicane
- Comparison between dipoles scheme and curved solenoids scheme
- Summary

Requirement for charge selection

- At target, both $\pi+/\pi-$ are produced, but one specie muon is used for experiment at a time [very low background of the other].
- In conventional neutrino beam lines, magnetic horns focus only one charge; in solenoids-based capture system (such as MOMENT), both charges are focused equally.
- Designing a charge selection scheme:
  - High effectiveness of selection (purity)
  - High transmission efficiency (and low emittance growth)
- Discarded pions or muons may be used for other purposes

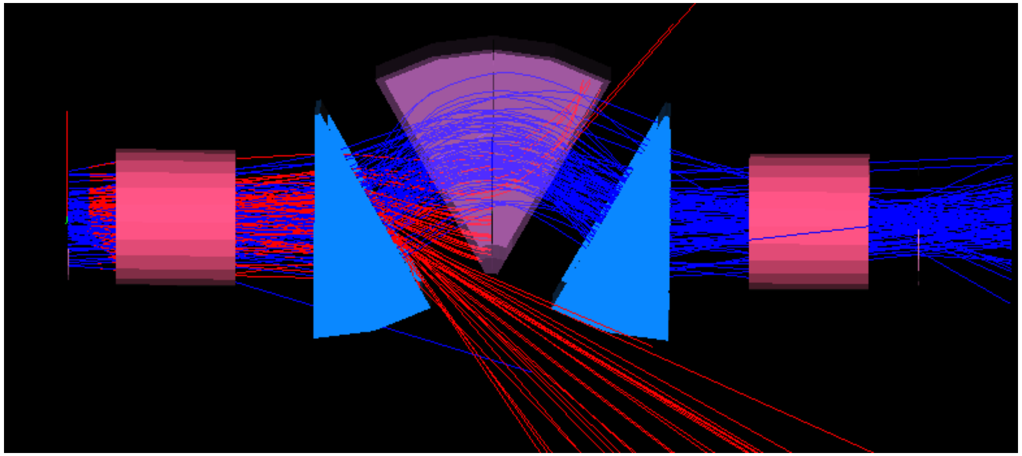
Layout of MOMENT



Two alternative charge separation locations A and B, separating either pions or muons of different charges.

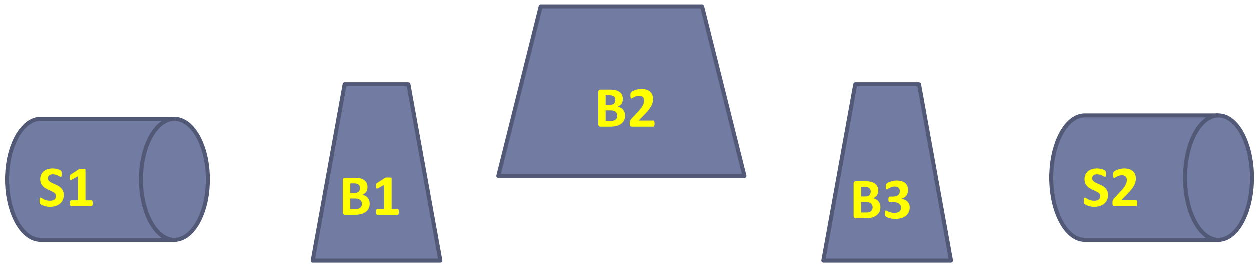
Charge selection by dipoles

- The chicane is composed of three combined function dipoles (superconducting, reference particle: -20°/40°/-20°). By adjusting the edge angles and gradients to make the required focusing in both horizontal and vertical planes.
- Wrong charged particles can be stopped or separated from the selected one.



Blue: pi+ red: pi-

- Challenges:
  - Very large apertures due to extremely large emittance (field overlapping)
  - Very large momentum range
- Beamline and parameters



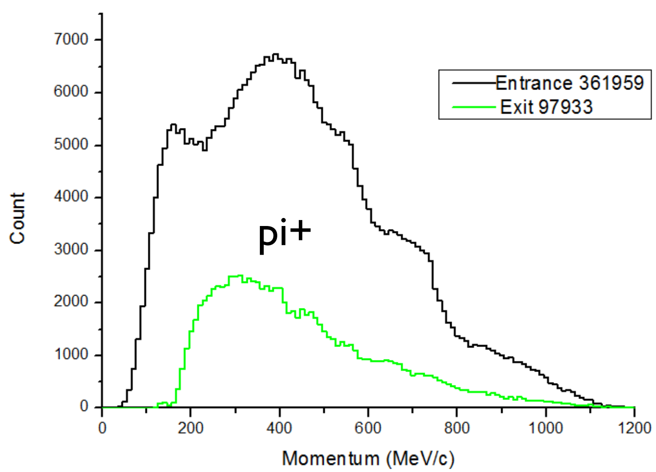
Reference momentum for mu+: 300MeV/c

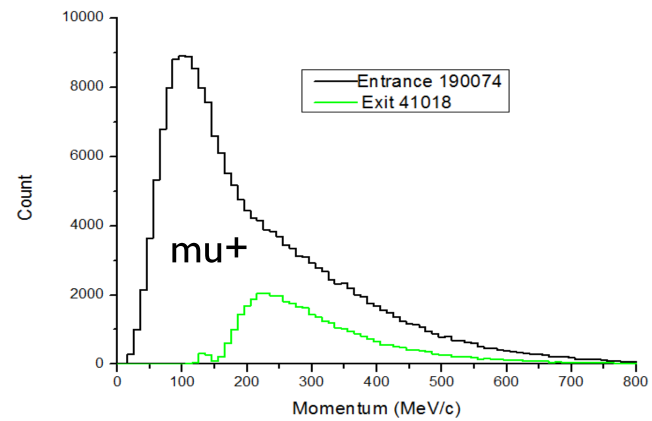
Element	Length (m)	B_0 (Tesla)	Gradient (m^{-2})	β_1/β_2 (mrad)	Gap/aperture (m)
S1/S2	0.56	3.40	-	-	600
B1/B3	0.3	-1.75	0.55	154	600
B2	0.6	1.75	0.19	306	600

Simulation results

- By using G4Beamline

	Entrance	Exit	Transport efficiency
π+	361962	98043	27.1%
π-	146706	21	
μ+	190077	61828	32.5%
μ-	98892	1	





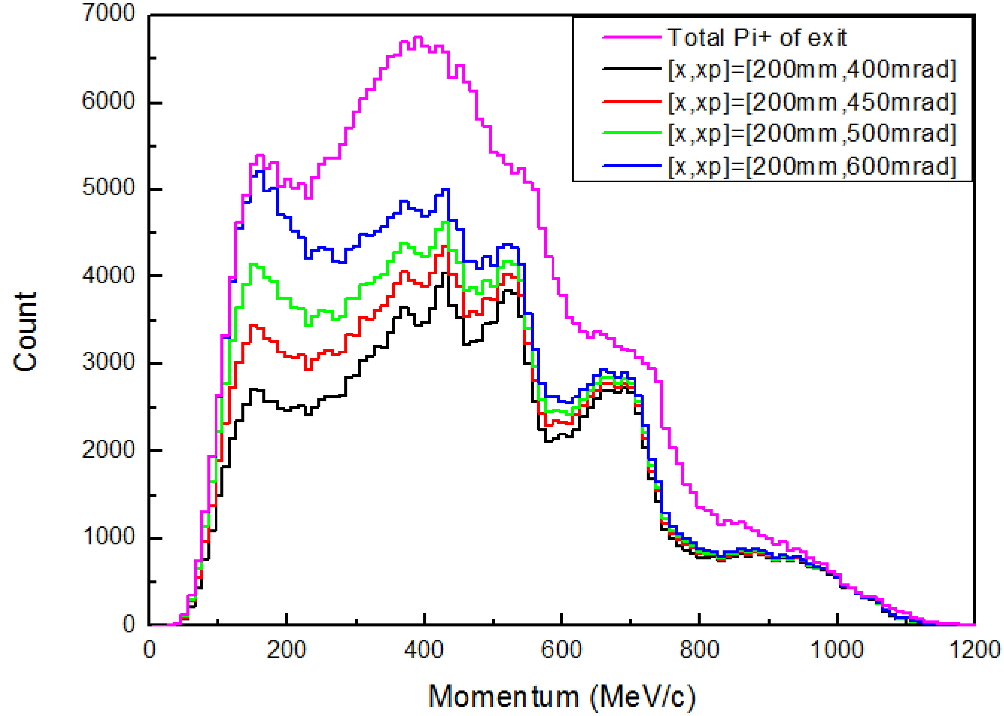
Analysis of the distribution of pi+ at the end of capture

- From the target simulations

Limit (x*xp)	All energy	ε_{RMS} (πmm.rad)	150-500 (MeV/c)	ε_{RMS} (πmm.rad)	150-700 (MeV/c)	ε_{RMS} (πmmrad)
Total emittance	361959	25.0 25.0	205967	27.7 27.7	287079	26.3 26.3
200*600	284322	17.9 17.6	159204	19.1 18.9	221796	18.1 17.9
200*500	255311	16.0 15.7	138706	16.7 16.6	198655	16.0 15.8
200*450	234018	14.7 14.4	124349	15.1 15.0	182013	14.7 14.5
200*400	209452	13.2 12.9	108183	13.4 13.3	162864	13.0 13.0

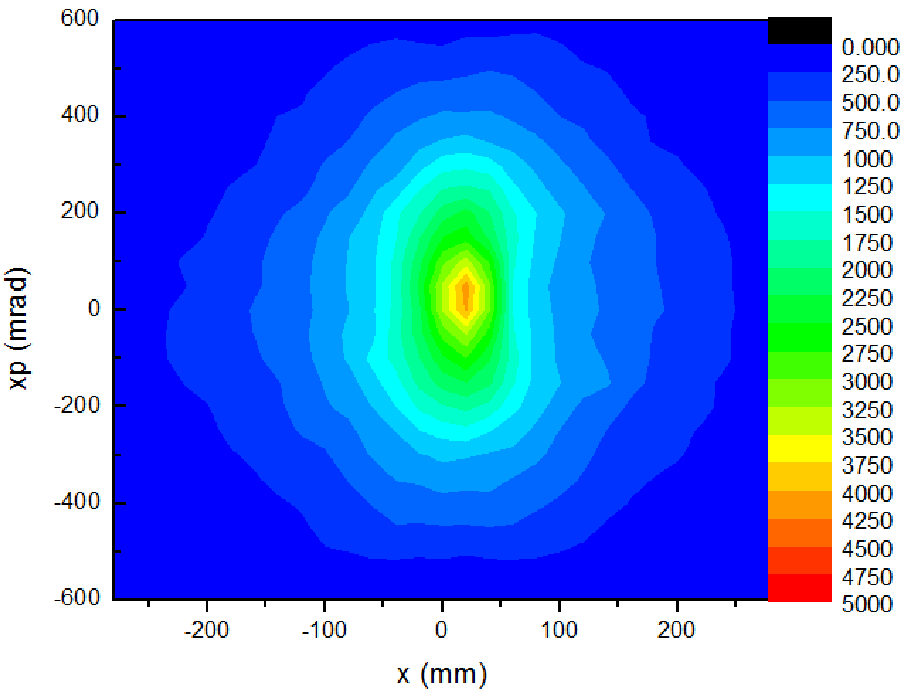
Distribution of pi+ at entrance of selection section

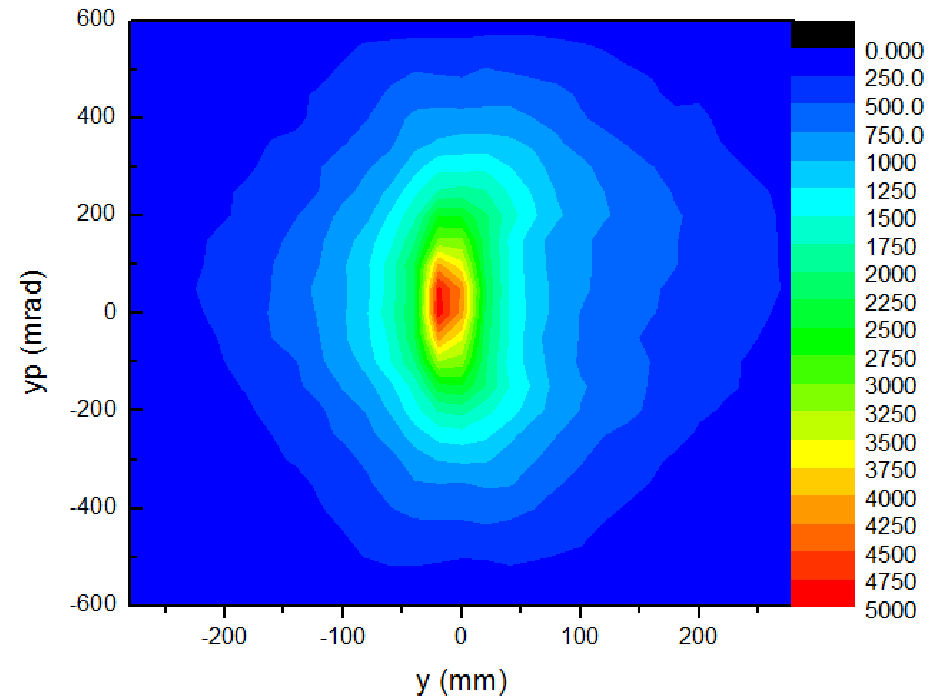
- Momentum spectrum of different transverse emittance



The distribution of pi+ at entrance of selection section

- The density of x and y phase plane

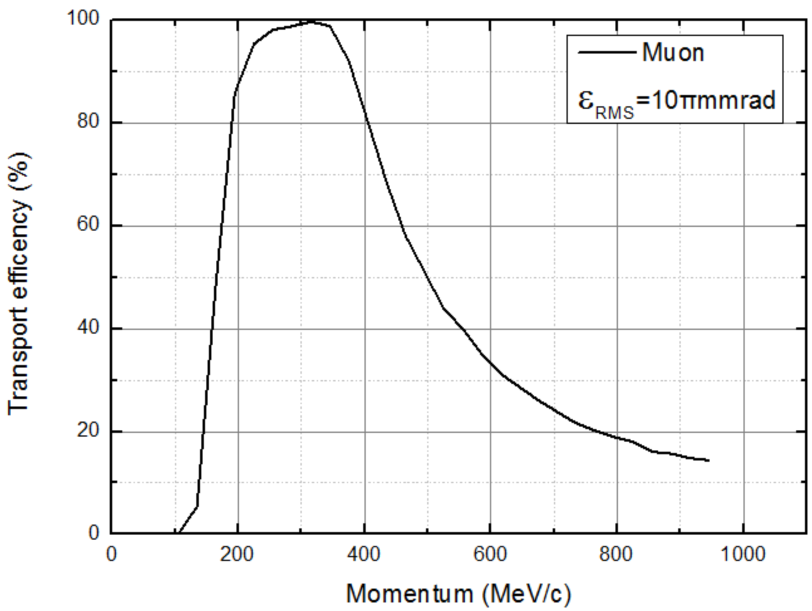


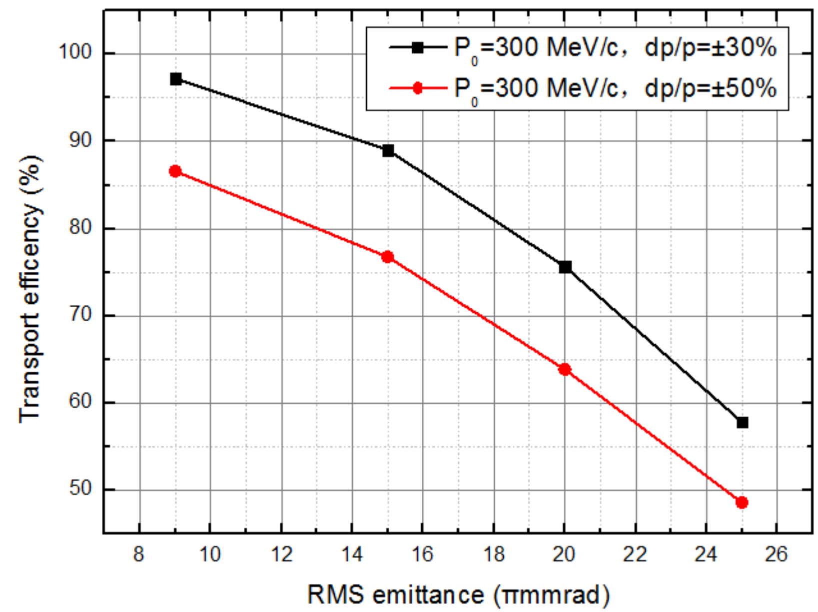


Considering the acceptance of the downstream beamline, we choose an emittance of 200mm*450 mrad to transport, it will not cut the core of the beam

Analysis of particle loss

- Mu+ transport efficiency VS momentum and emittance

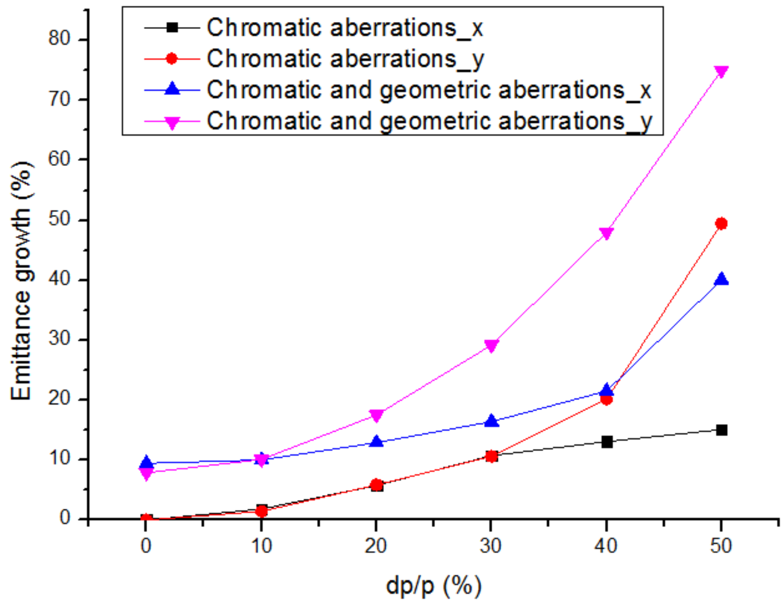




The curve is obtained from linear lattice, the efficiency is ideal at momentum spread 200-400 MeV/c, but we need to accept wider momentum, nonlinear lattice will be a good choice.

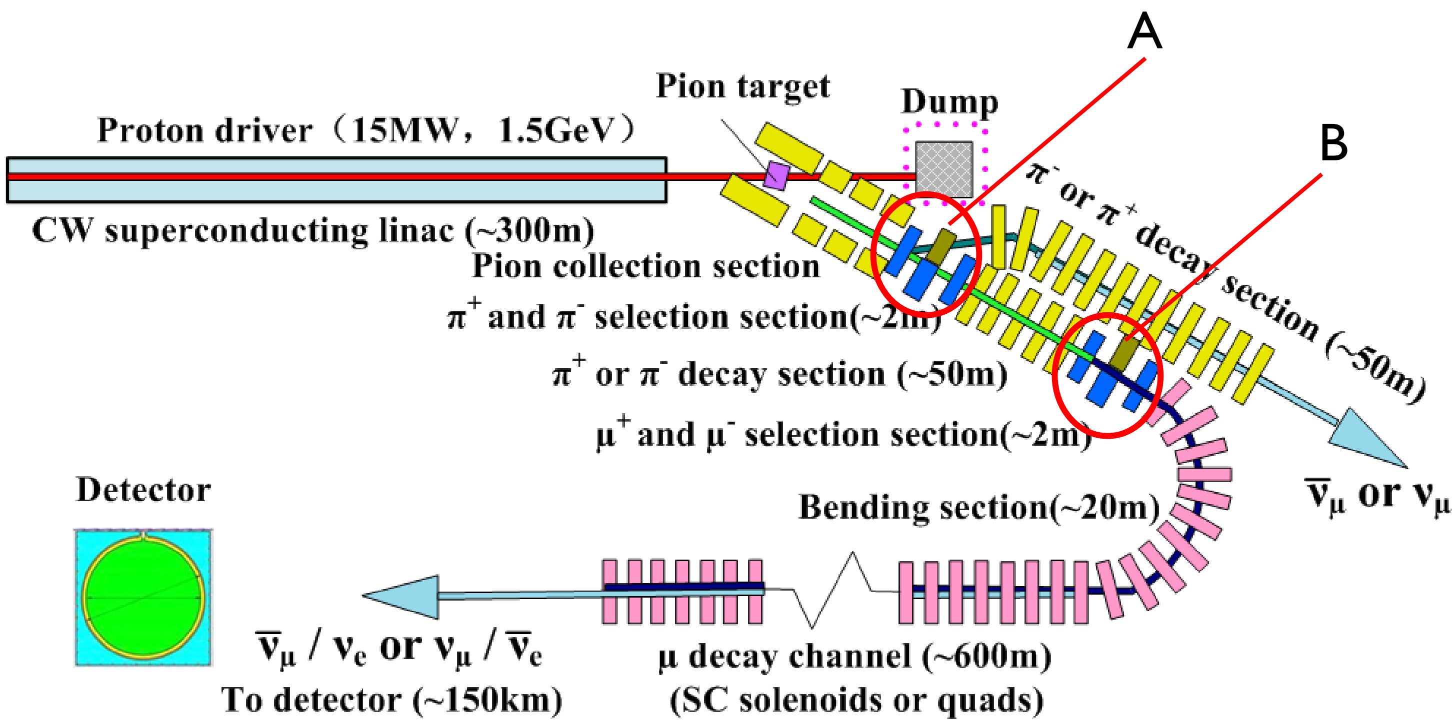
Analysis of particle loss

- Emittance growth due to higher order effects

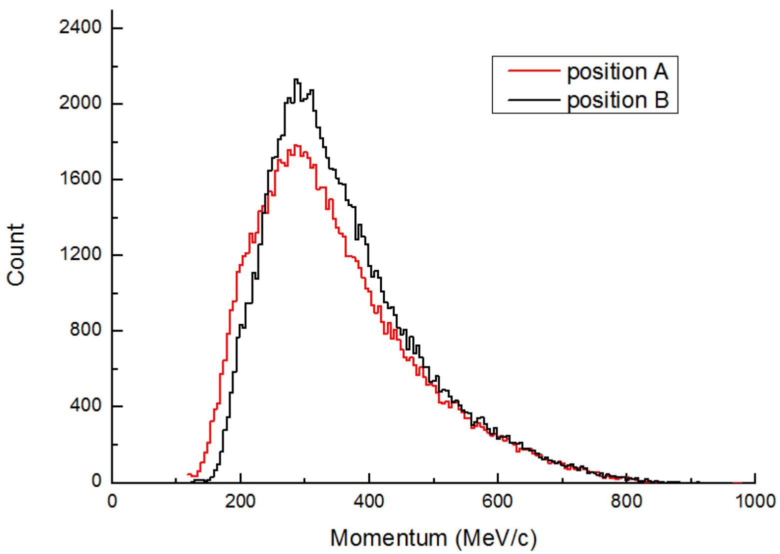


- The curve is produced with ε_{RMS}=10 πmm-rad,

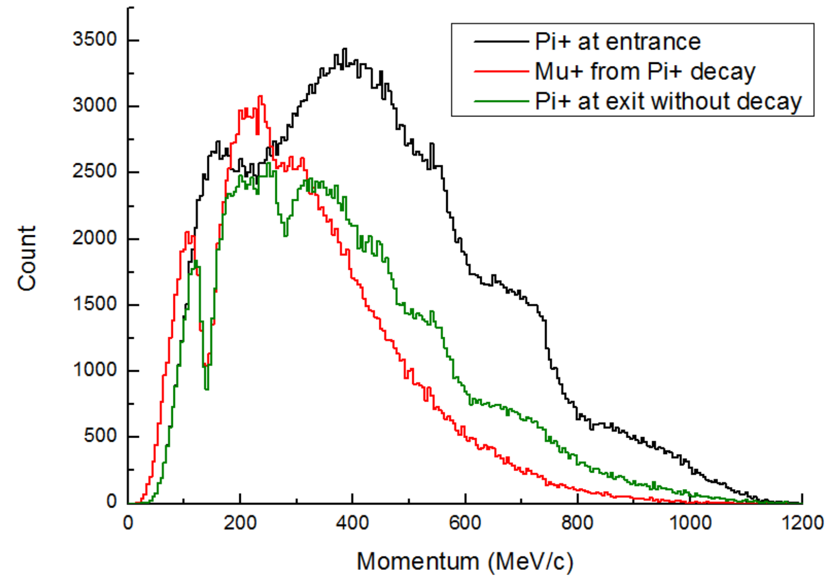
Charge separation at different locations



Charge selection at different locations



Muon spectrum at the entrance of muon decay section



The red line is from the decay of green line

- There is no large difference between two locations, because many high energy pions are lost in the pion decay section.

Separation by curved solenoids

- Scheme sketch (R. Palmer)

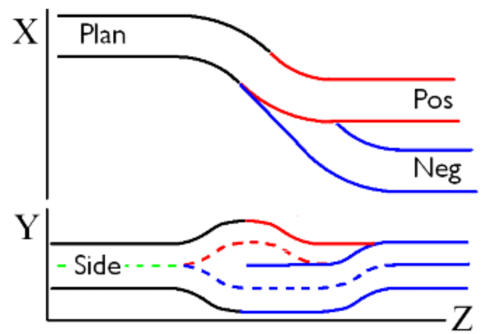


Figure 1: Schematic of charge separation method.

- To match the curved solenoid with the straight parts at both ends, the length of curved solenoid L should be multiple of λ

$$L = n * \lambda \qquad \lambda = \frac{2\pi P_z}{B_\phi c}$$

- The beam should be bent back to cancel the dispersion effect.

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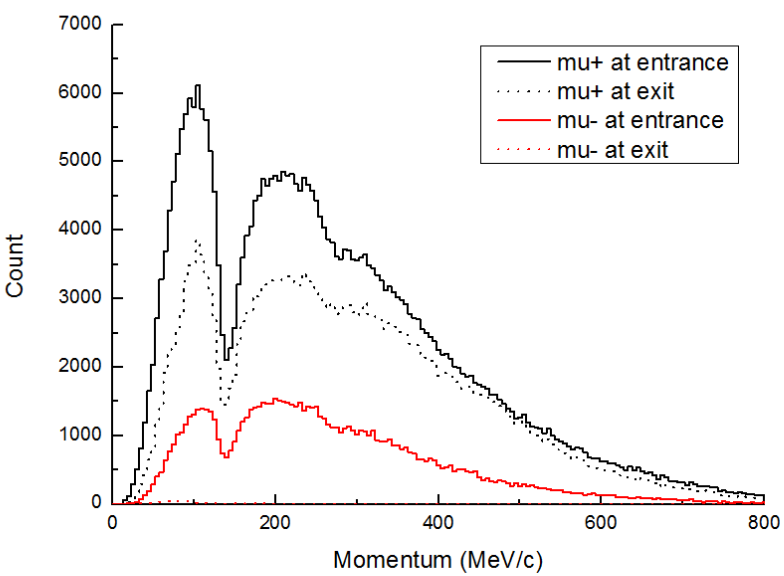
Simulation result by G4Beamline

Parameters and result

Charge selection comprised by 16 unit elements

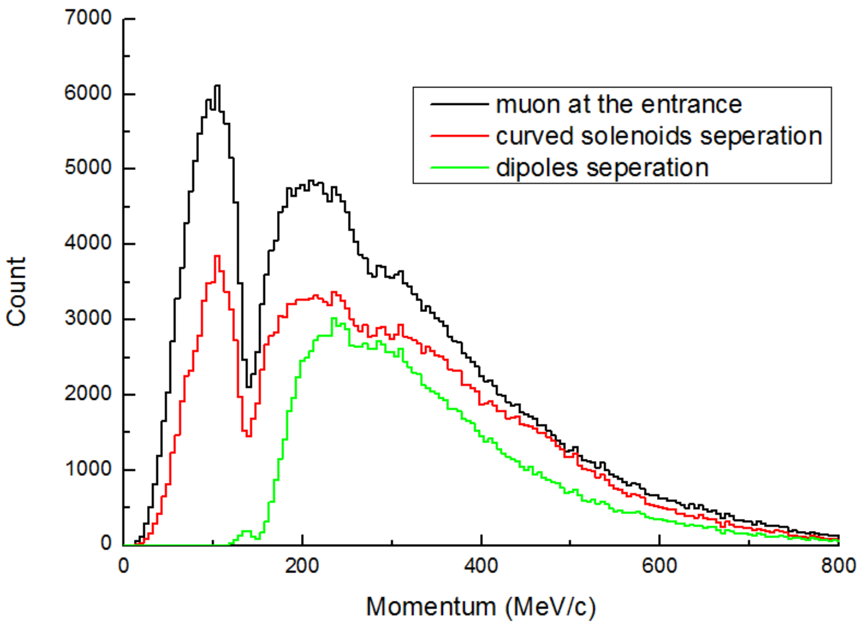
Unit element： 100mm Drift + 500mm Solenoid ($\Phi=700$, Bz=3.7T, By=0.25T)



	Muon+	Muon-
Entrance	348821	91399
Exit	251018	630
Transport efficiency	72%	0.69%

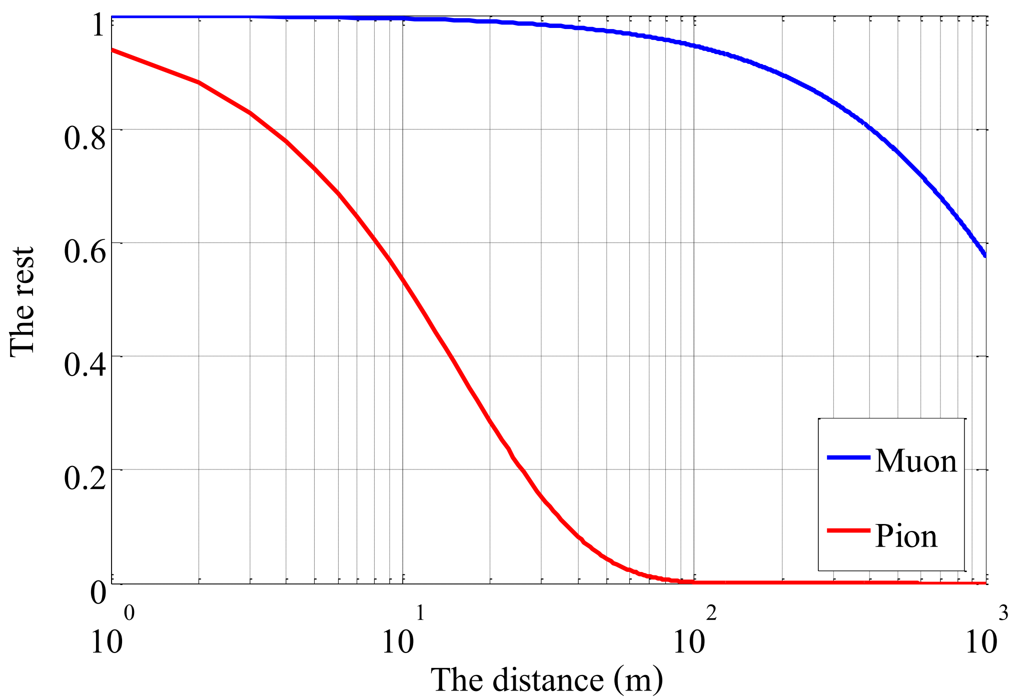
Comparison between curved solenoids and dipoles

	Curved solenoids	Dipoles
Transport efficiency	72.0%	42%
Emittance growth in x plane	60.0%	47.1%
Emittance growth in y plane	60.0%	24.8%



Decay within the selection section

- The decay curves of pion and muon



The reference momenta of muon and pion used in the curve are 291MeV/c and 285MeV/c respectively, corresponding to 300 MeV neutrino.
(Lifetimes of rest pion and muon: 26 ns and 22 μs)

It looks acceptable to have in-course decays.

Problems/limitation

- How to reduce the effects by Second-Order Chromatic Aberrations and Second-Order Geometric Aberrations? Then we can reduce the emittance growth.
- The realistic transport situation is even worse than the present study, due to the overlapping of the fringe field between adjoining dipoles (very large aperture).
- To enhance the acceptance on momentum range, nonlinear field should be introduced, which is still under study.

Summary

- Charge separation methods based on both dipole chicane and curved solenoids have been studied, with more details on the former.
- Selection for both pions and muons are possible.
- For relatively narrow momentum range (300±30%) MeV/c， the results are not so bad, but we hope to increase it to about ±50% by introducing nonlinear fields (more complicated, study just started).
- Very large transverse emittance has important impact to the selection, some pre-collimation or low transmission efficiency has to be accepted.

Thank you for attention!