Charge separation in the muon collider front end

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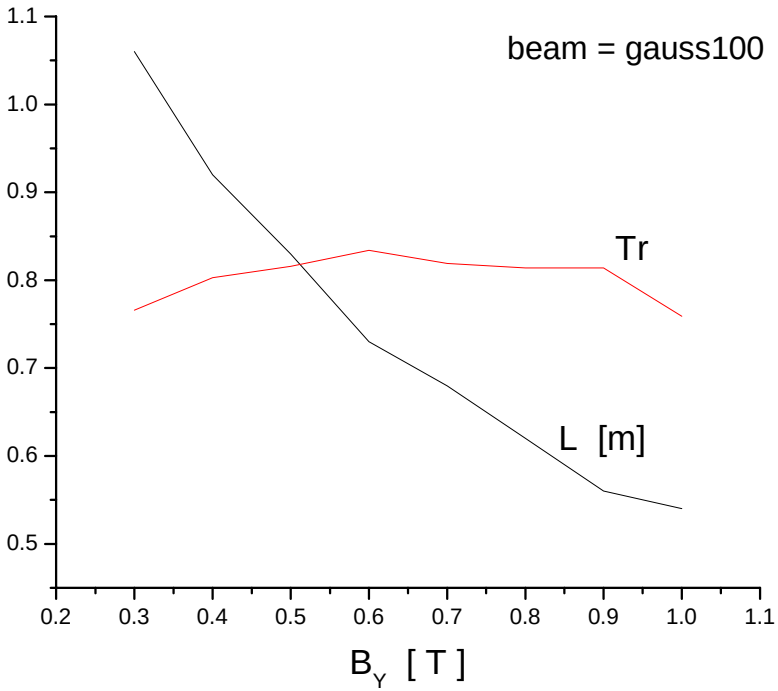
Introduction

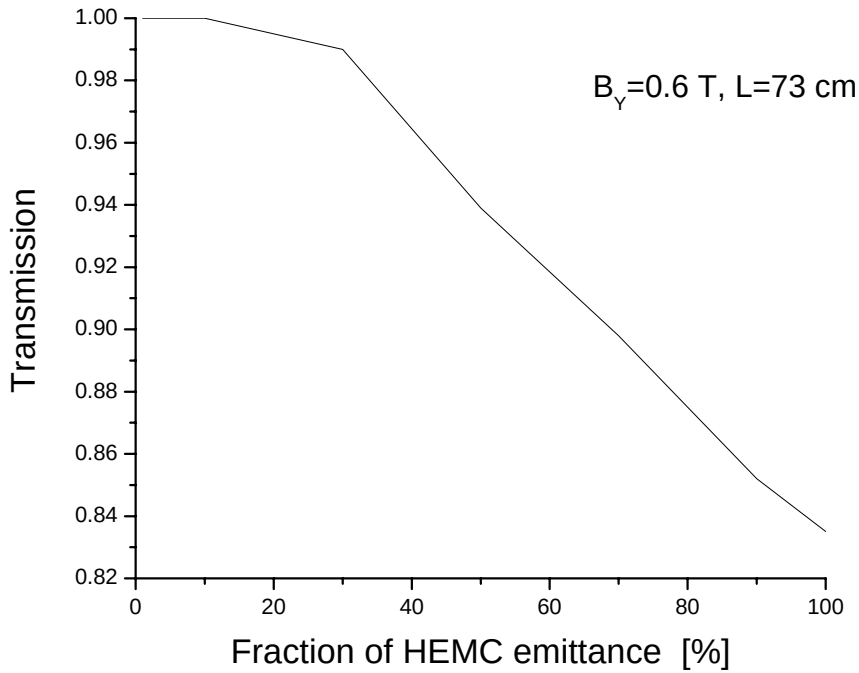
- positive and negatives muons are born together
- most collider scenarios need to separate the charges
  before start of 6D cooling
    - HEMC scenario: before first Guggenheim
    - LEMC scenario: before HCC
    - MEMC scenario: may also need it (if it uses HCC)
- make preliminary investigation of three possible methods
    1. dipoles
    2. RF deflection cavities
    3. bent solenoids
- using HEMC parameters: ε_{TN}= 12 mm, ε_{LN}= 41 mm
- idea: identify most promising approach now
  make more detailed studies later

1. Dipole model

- ICOOL is not an ideal tool for this example
  - uses Frenet-Serret coordinate system
  - one sign follows the curvature in the coordinate system
  - other sign has distorted looking distribution
- wrote new cartesian tracking routine for this study
- start with constant dipole field
- use 30 cm radius exit holes for two separated beams
- adjust dipole length to get ±31 cm center separation

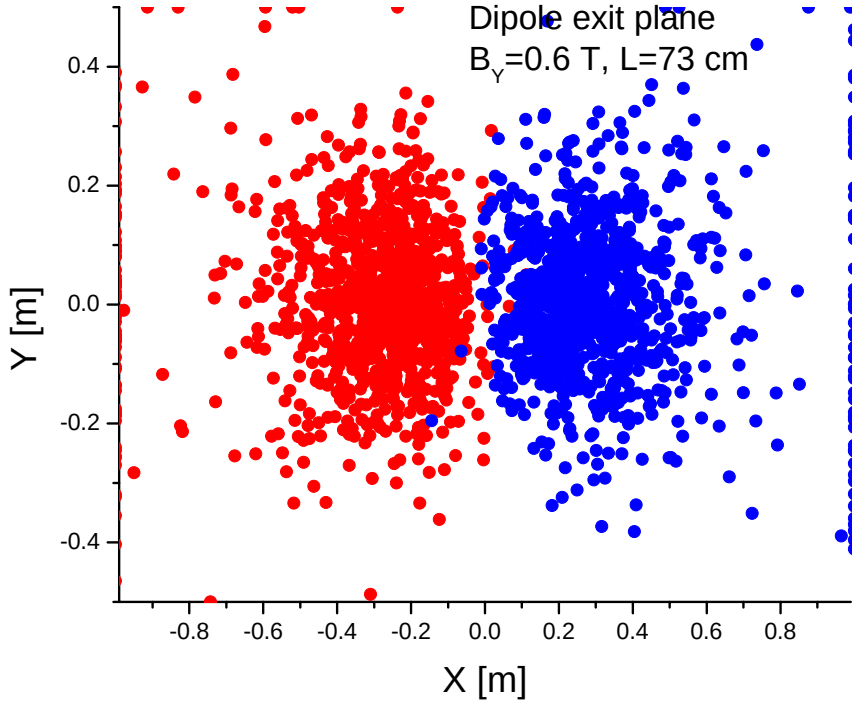
Optimization

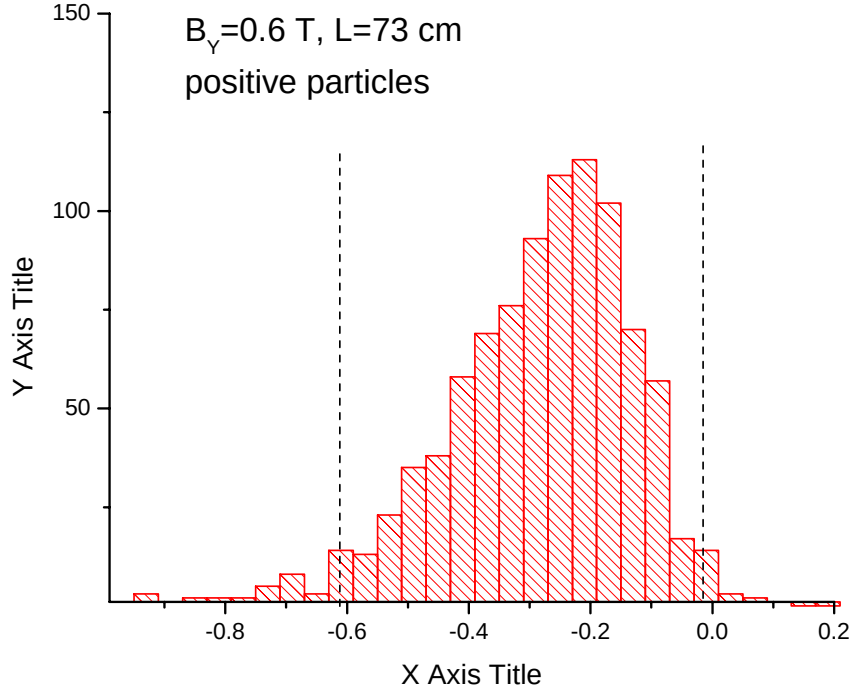




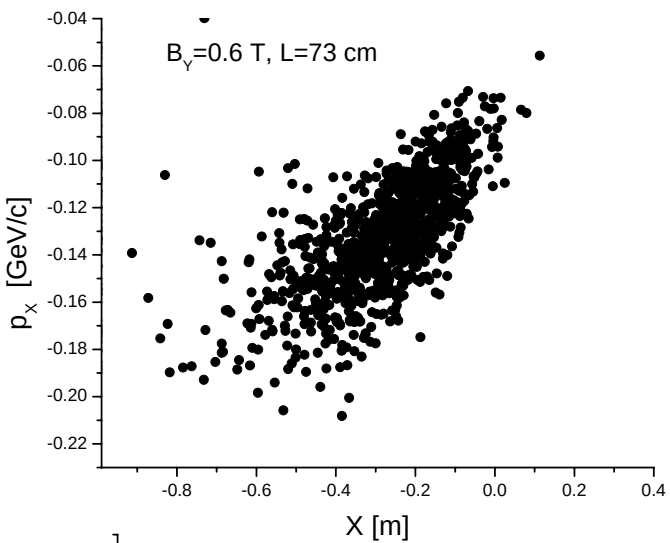
- reasonable separation acceptance (~84%) for HEMC beam

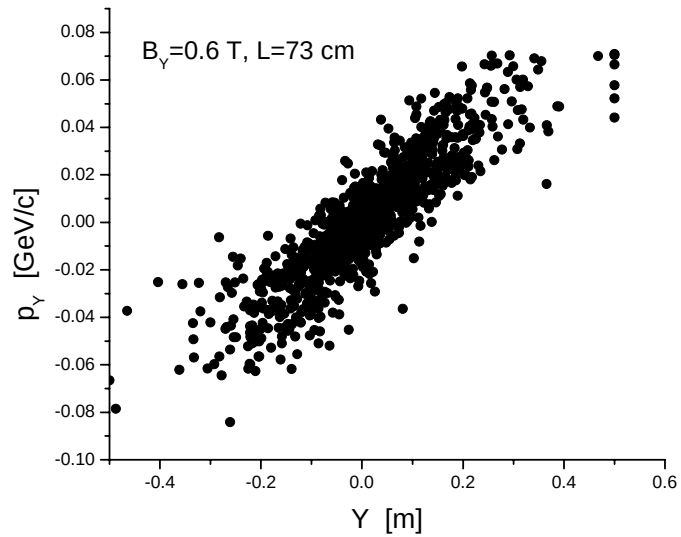
Exit plane distribution

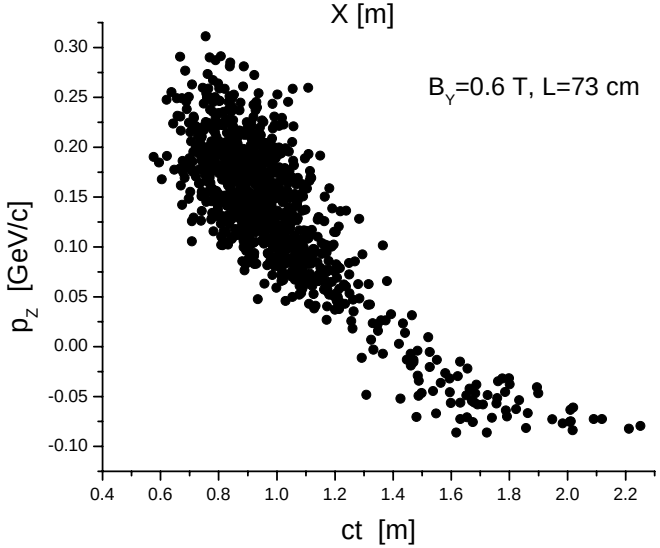




Phase space at exit window

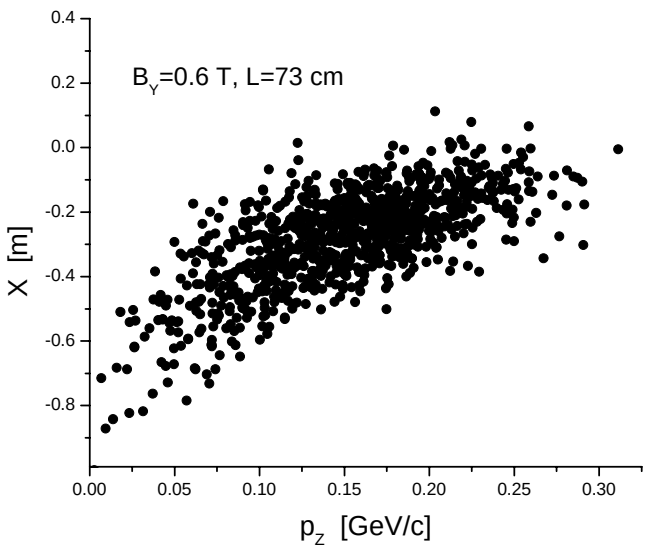


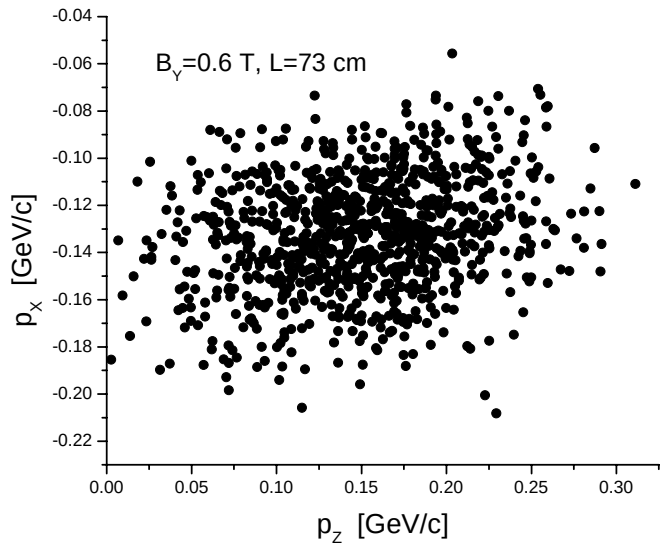




needs focusing, but that hurts separation ?
needs RF or longitudinal preconditioning,
but that stretches system out ?

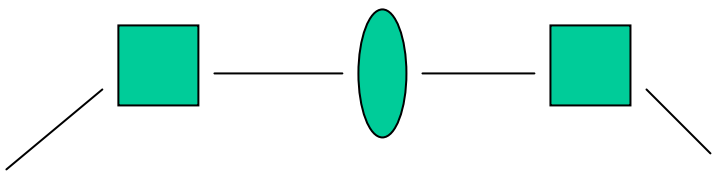
Dispersion at exit window





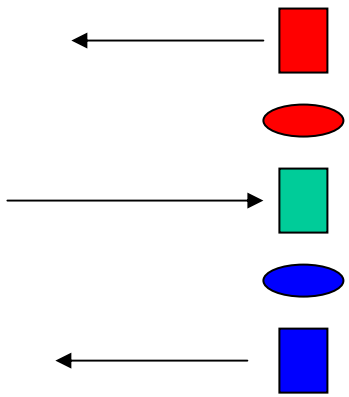
accepted beam is dispersive

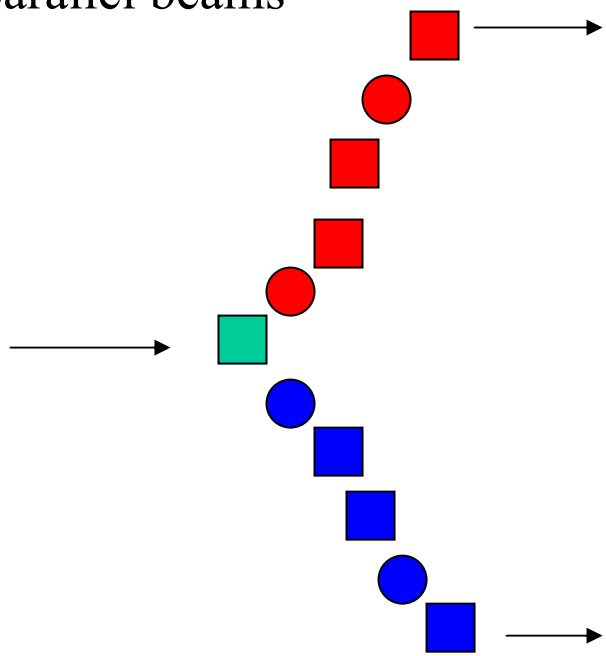
Removing the dispersion (quads)



classic achromat
both bends must be in same direction
e.g. LQ=20 cm, BQ=0.34 kGs, rQ=30 cm
LD=64 cm, BD=7 kGs, d=20 cm

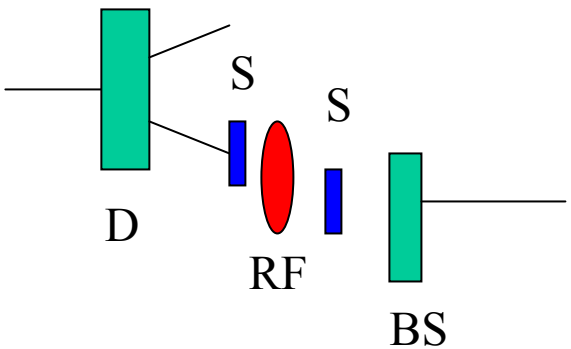
Configurations that produce 2 parallel beams





long channels
also need to include
focussing
RF cavities

Removing the dispersion (bent solenoid)



- try to get back to solenoid channel as quickly as possible ?

e.g. ramp solenoid field to 3 T in 40 cm
1 m of 201 MHz RF

- use bent solenoid to bend beams parallel & remove dispersion

L_{BS} = 2.36 m, angle = 40.6°

Results

statistically removes dispersion
Tr = 77% of beam exiting dipole window
ε_{XN} : 24 → 52 mm
ε_{YN} : 12 → 49 mm
ε_{ZN} : 35 → 71 mm

- unacceptable emittance growth

Dipole summary

- possible approach
- expect additional losses
  - capturing beam in exit channels
  - transporting beams apart
  - removing dispersion
- must have proper matching from solenoid channel to dipole- quad channel and back again
- must include realistic dipole model including fringe field
- needs a lot more work

2. Deflection cavity model

- avoids difficulty of introducing RF in other methods
- looked at several arrangements of TE and TM cavities

(1) string of TE cavities doesn't work

violates Panofsky-Wenzel Theorem

confirmed in simulations using TE_{011} rectangular cavities

constant E field along x

(2) string of TM cavities

(3) TM cavities with drift spaces in Alvarez-like arrangement

Cavity frequency

- $t0 \equiv$ time between bunches of given sign crossing given cavity
  want cavity to go thru n cycles during t0
  $\rightarrow$ that cavity has same effect on each bunch in train
  $t0 = 1.5\ m / \beta\ c = 5.63\ ns$

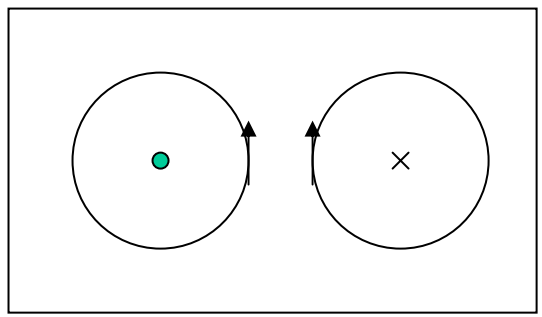
n	f [MHz]	λ [cm]
1	178	169
2	355	84

Channel of TM cavities

- try TM_{210} rectangular cavities

  has B_Y field along particle axis
- same cavity mode used for crab crossing, but 90° phase shift
- needs $w > \lambda$ for resonance
- tried f=355 MHz, λ=84 cm, G=30 MV/m

  d=25 cm, w=100 cm, h=77 cm
- adjusted $\Delta\varphi$ to get equal, opposite deflections for + and –
- got ±30 cm separation in 80 cells with ideal beam
- total channel length = 20 m

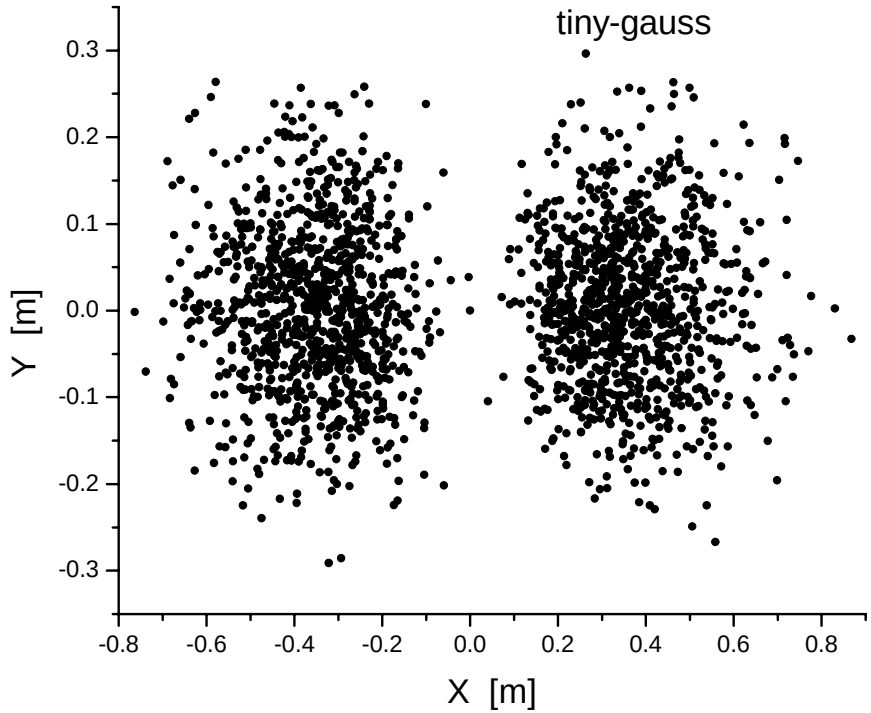


Alvarez arrangement

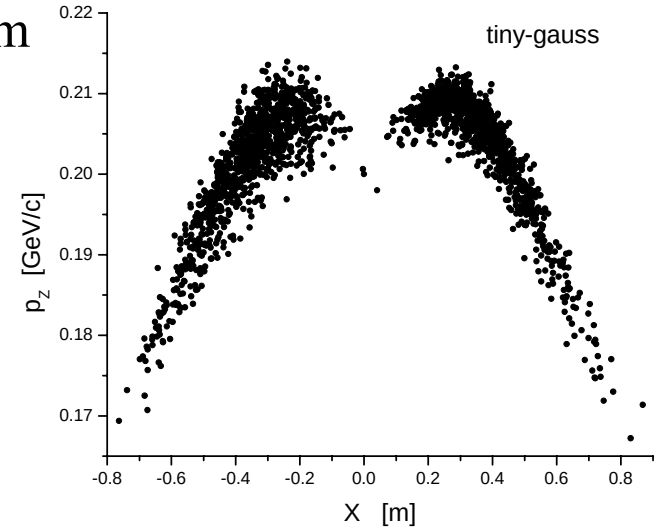
- tried to shorten TM channel using Alvarez-like arrangement
  shield out field reversals with drift spaces
- use TM_{210} cavities discussed previously
- space cavities $\beta\lambda_1/2$ apart
  given bunch sees same field in every cavity
  cell = 25 cm cavity + 41 cm drift
- adjusted $\Delta\varphi$ to get equal, opposite deflections for + and –
- got ±30 cm separation with 11 cells with ideal beam
- total channel length = 7.3 m

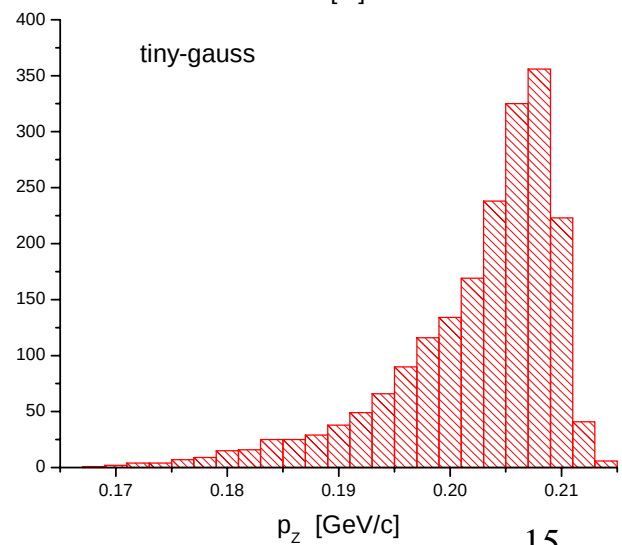
Gaussian beam

- run Alvarez channel with 1% HEMC gaussian beam



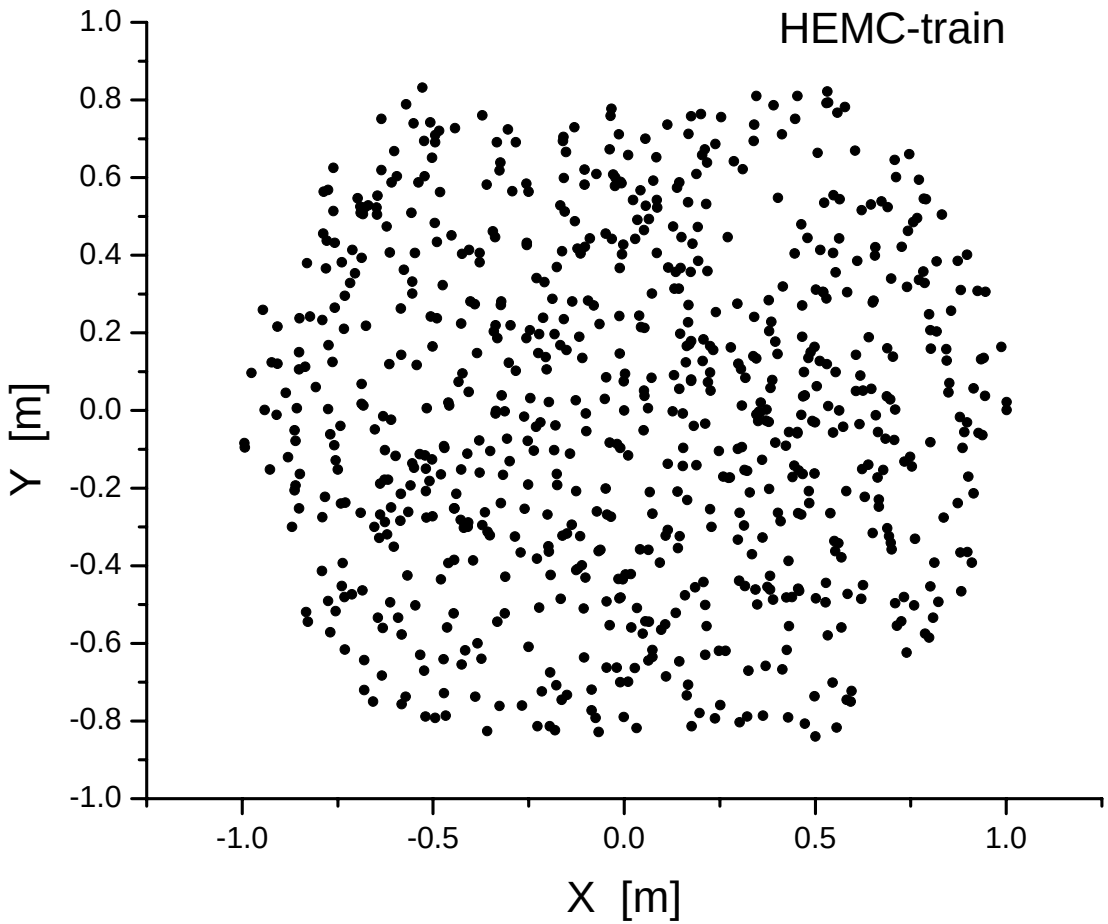
good separation along x
Tr = 99%





n.b. asymmetry in p_Z

Full gaussian beam



no separation !!
Tr = 37%

No good for us

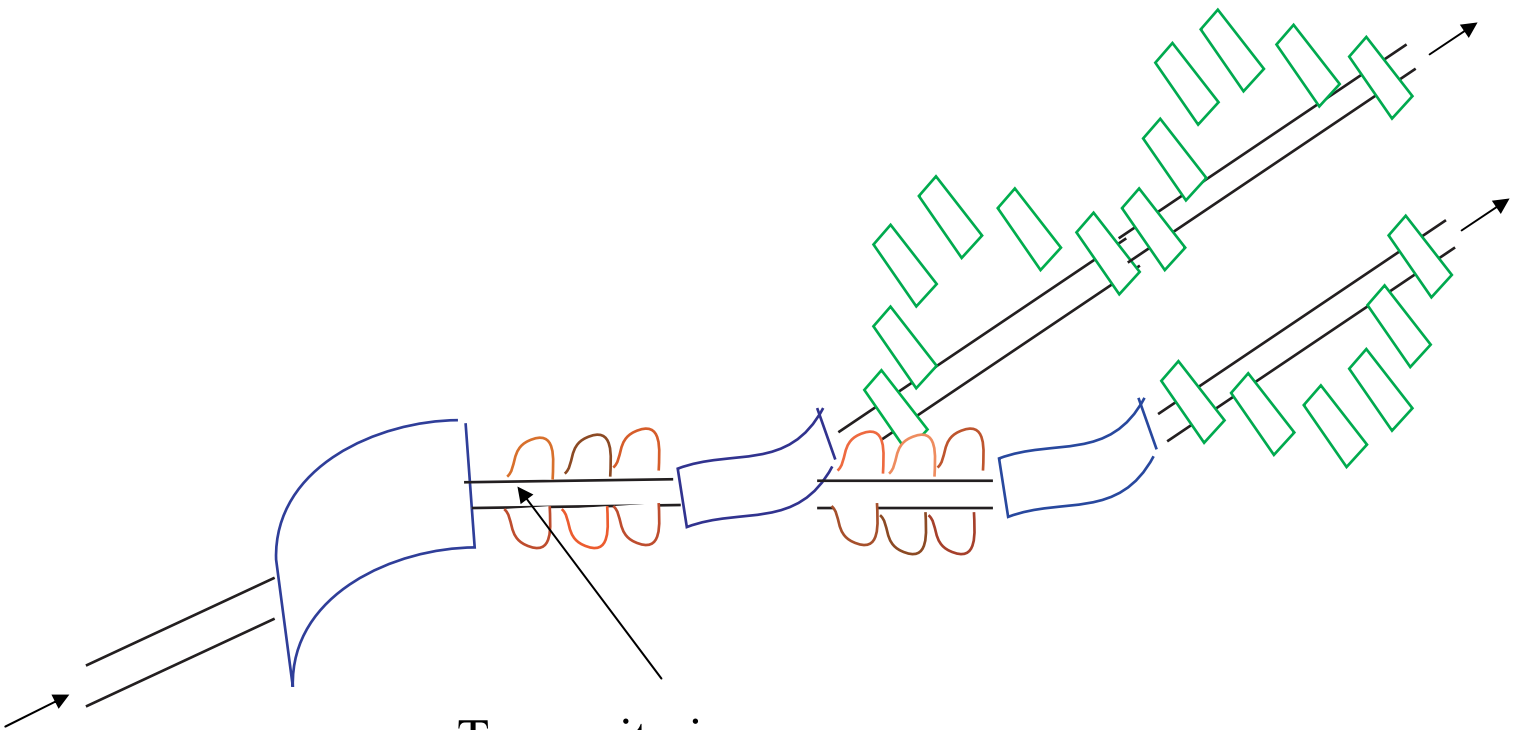
3. Bent solenoid model

- try using simple bent solenoid, ICOOL model BSOL(2)
- on-axis fields have $\Delta\tanh(s)$ (or constant) dependence
- off-axis fields comes from multipole expansion
- look at channel with pair of bent solenoids

  first bent solenoid does separation

  second bent solenoid removes dispersion

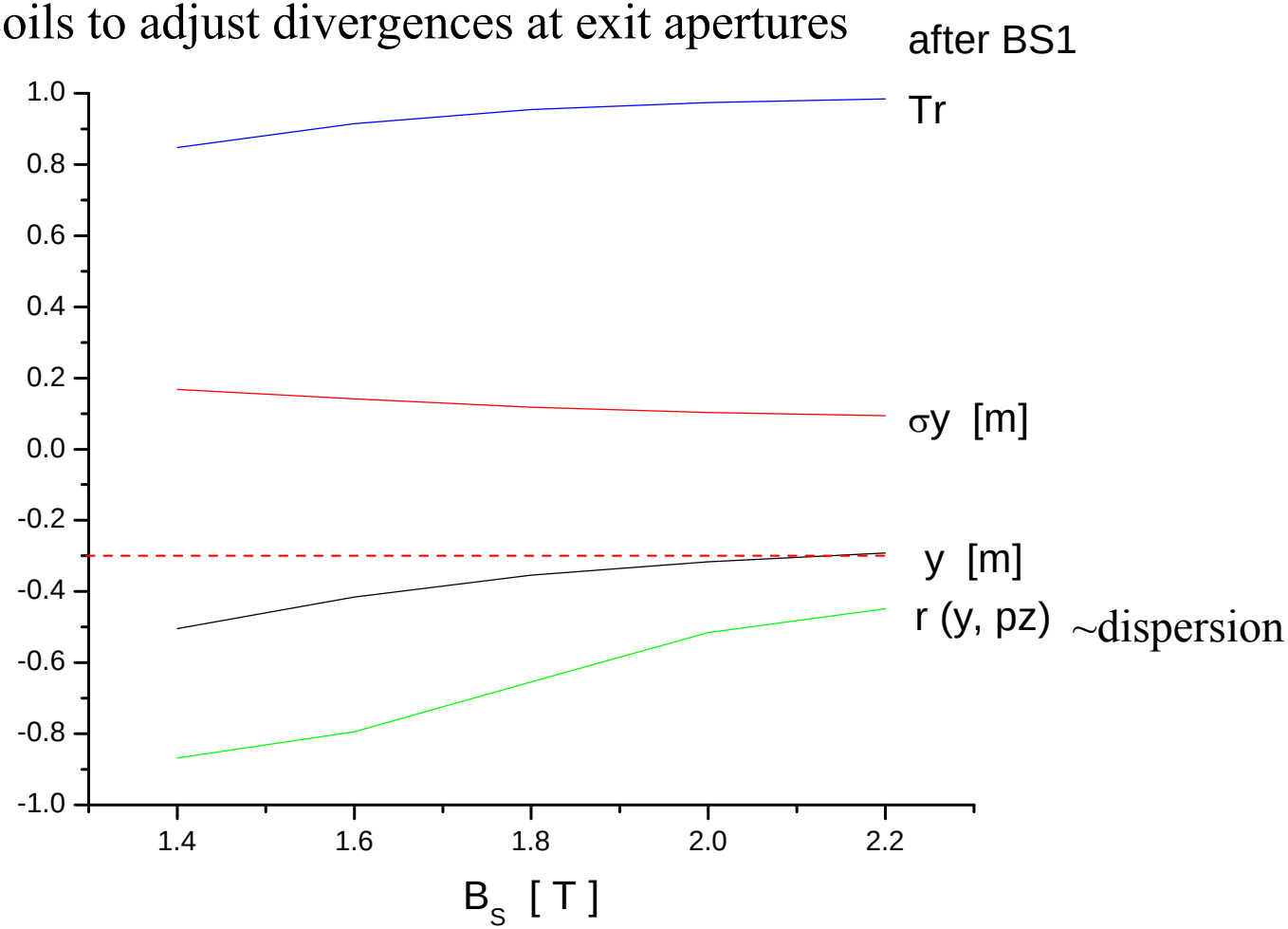
Schematic horizontal layout



Two exit pipes
separated vertically

1st bent solenoid optimization

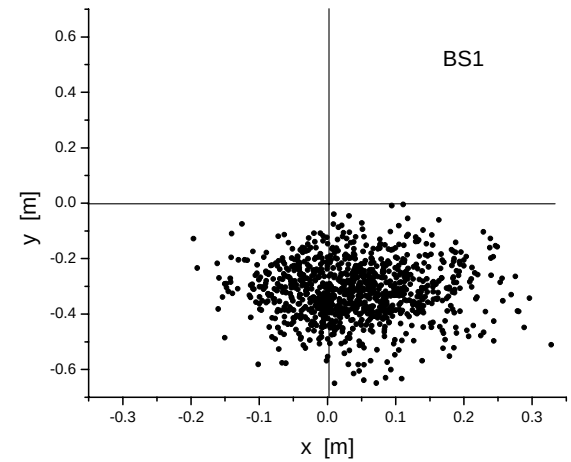
- used BSOL model 2 in ICOOL (use version ≥3.17)
- constant solenoid, no dipole field
- assume trim coils to adjust divergences at exit apertures

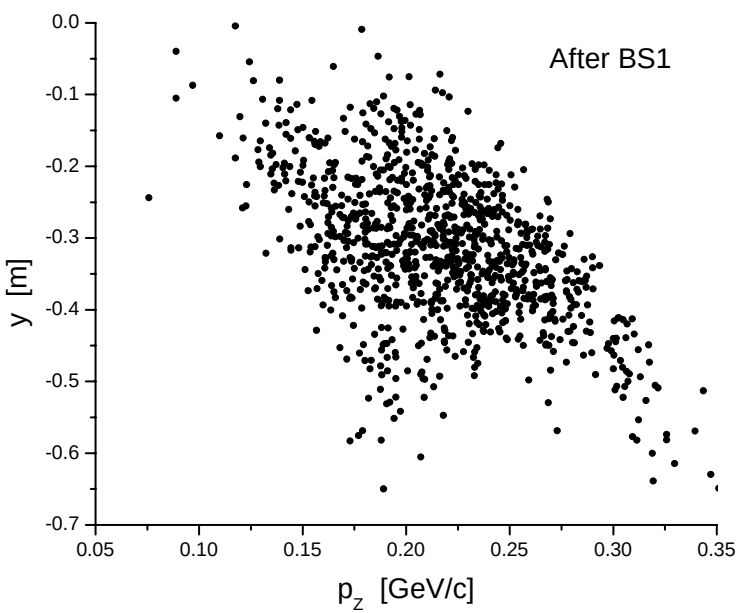


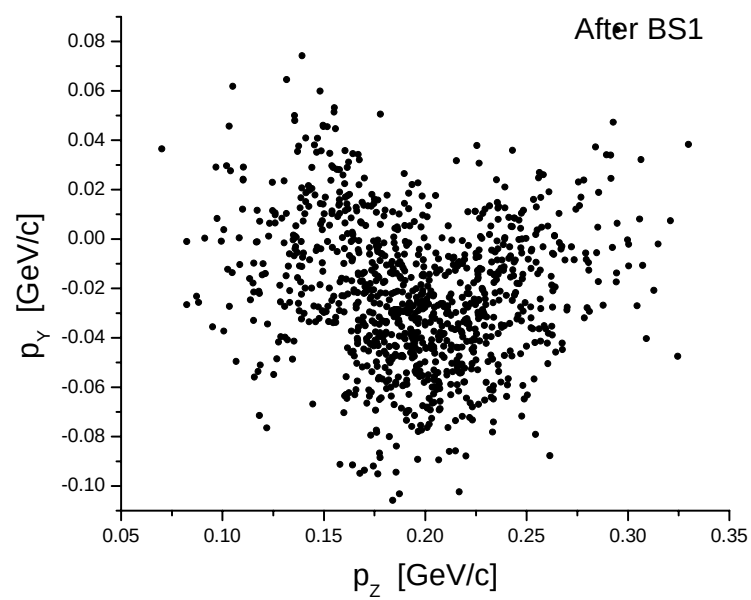
1st bent solenoid parameters

B_S=2 T, B_D=0 T, L=3 m, h=0.3 m^{-1}

HEMC beam

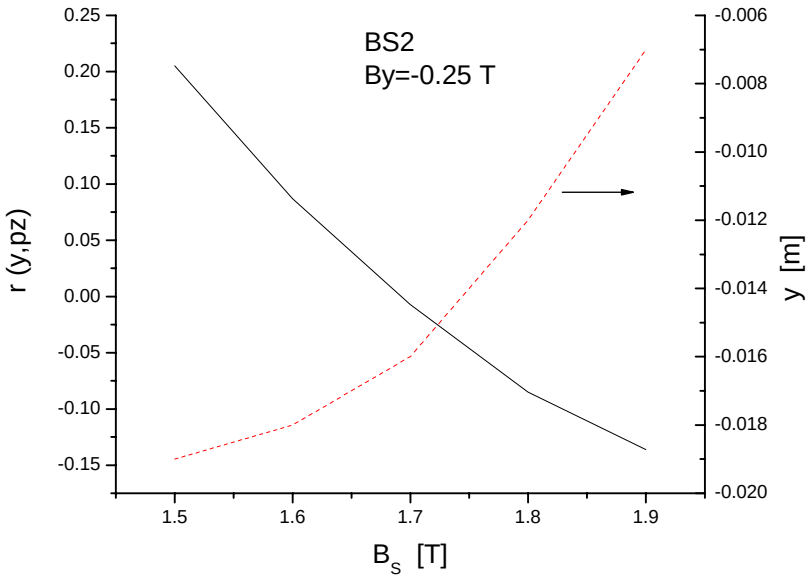


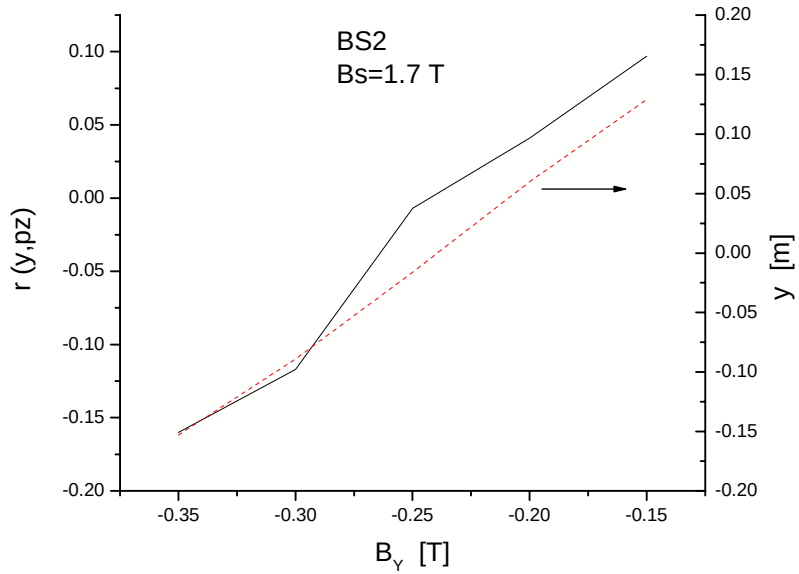




2nd bent solenoid optimization

- linear correlation coefficient r (y, pz) is proportional to dispersion
- use B_S to remove dispersion
- use B_Y to keep beam centered in y

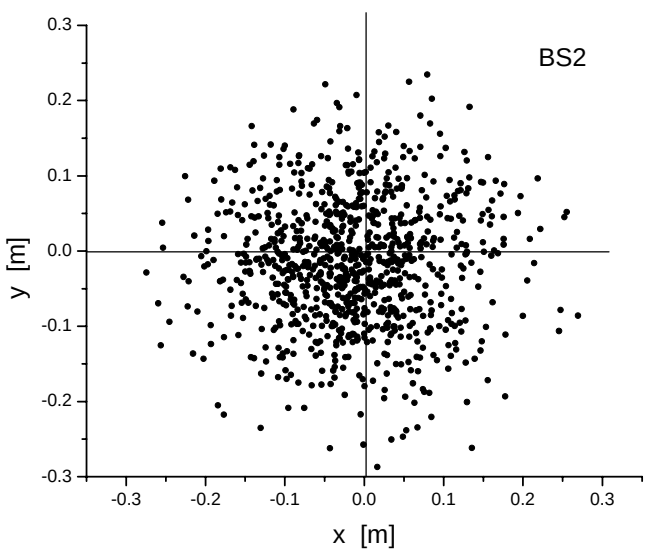


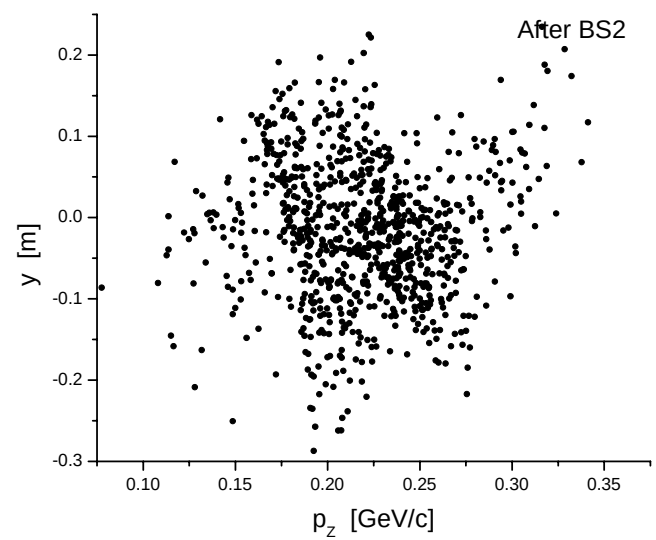


2nd bent solenoid parameters

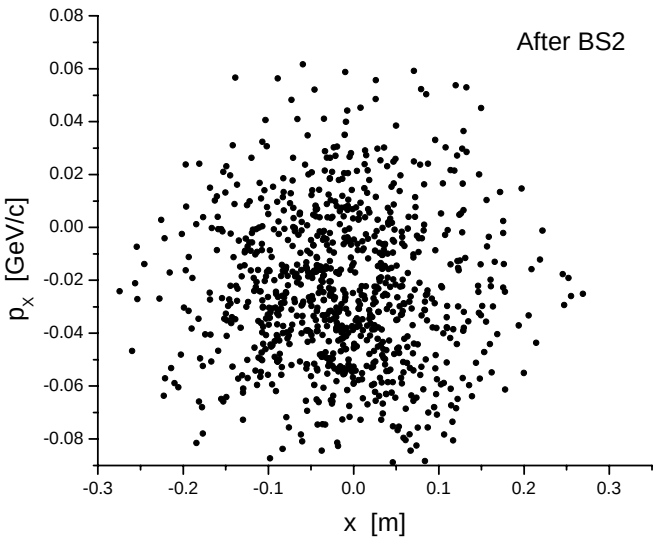
- used BSOL model 2 in ICOOL
- constant solenoid field
- Δtanh dipole field

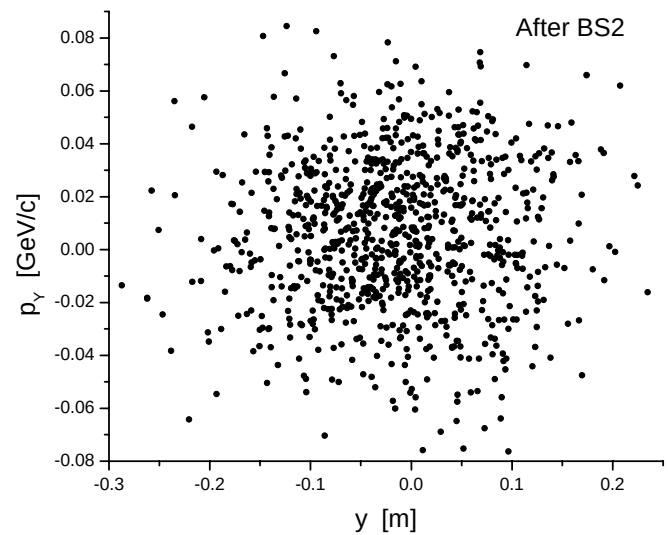
B_S=1.71 T, B_D=-0.24 T, L=3 m, h=-0.3 m^{-1}, L_C=2.5 m, Le=0.25 m, λ=0.2 m
HEMC beam

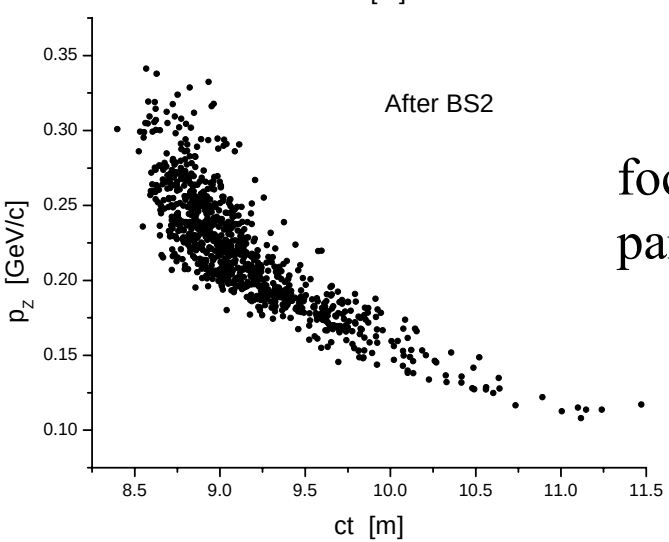




Final phase space







focusing is built in, transverse phase space OK
particles leaving bucket, need RF in bent solenoids ?

Bent solenoid results

- separation and transmission look good
- Tr = 90% of entrance beam
- statistically removes dispersion
- main issue here is emittance growth

ε_{XN} : 12 → 24 mm
ε_{YN} : 12 → 23 mm
ε_{ZN} : 41 → 54 mm

Conclusions

- dipole is possible, but needs lot more work & no clear advantage
- RF separation is not suitable for large emittance beams
- bent solenoid channels look most promising for our problem

  incorporate focusing with separation in a natural way

  still need a lot of work to add realism & optimize performance