Charge recombination for the muon collider-2

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AAG Weekly Meeting

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Introduction

- the two charged muon beams need to be recombined somewhere in the cooling channel
- take a first look here at what issues might be involved
- look at a design modeled on our charge separation design

  Norem matching (tapered bent solenoid field and curvature)

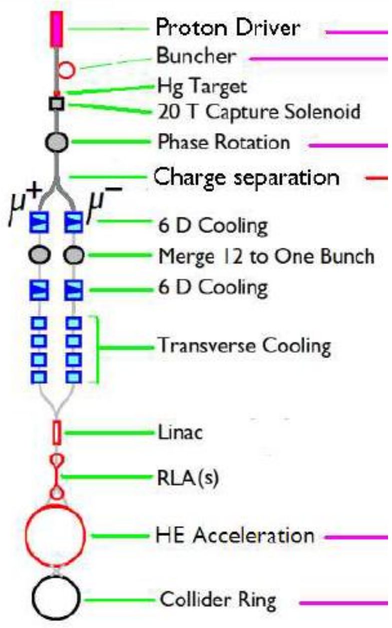
  two symmetric bent solenoids with opposite curvature

    θ_{bend}, Δy, and B_S are the same, but coil dimensions are different

    removes dispersion in exit beam

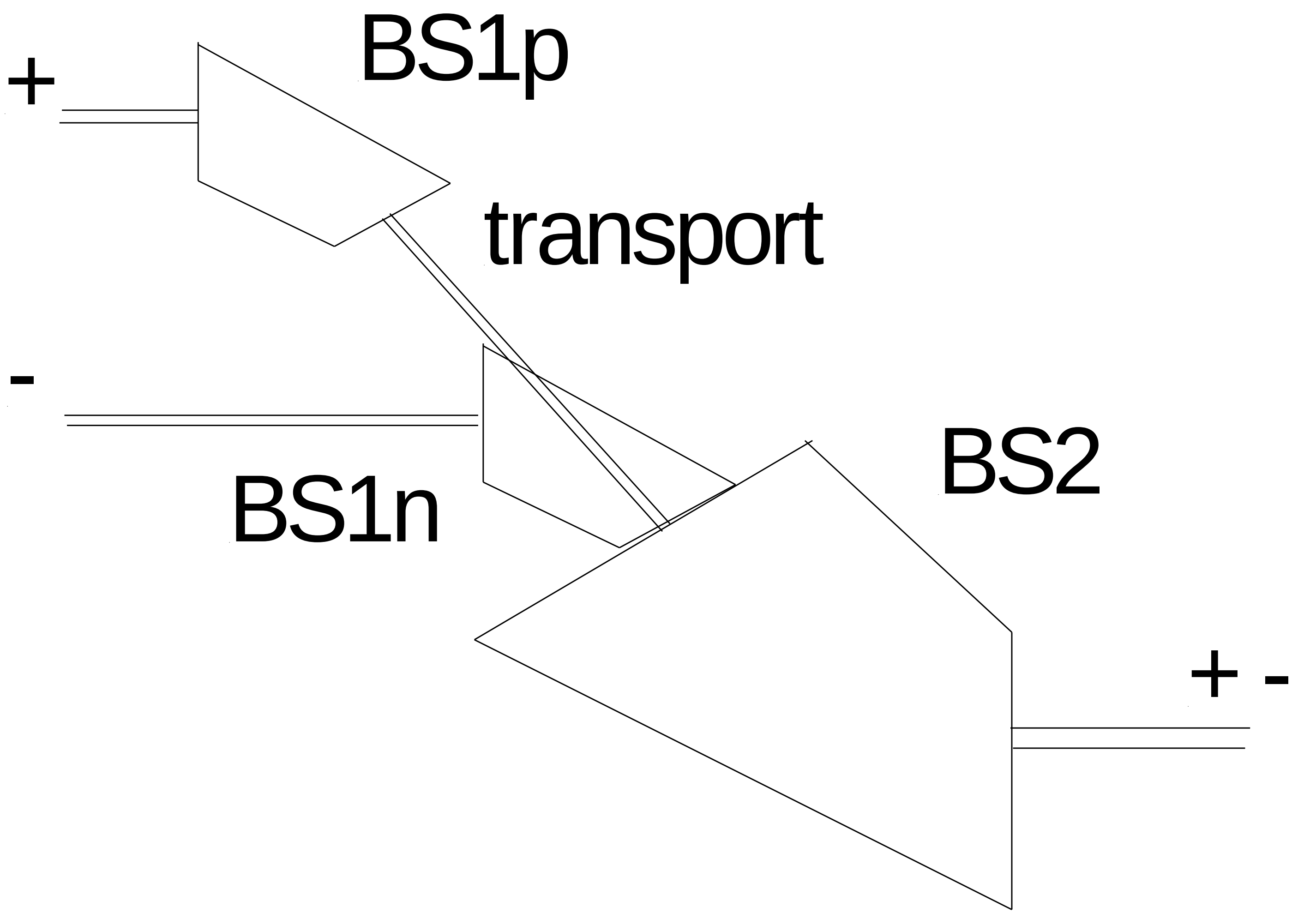
    minimize emittance growth in exit beam

  allow acceleration to higher momentum to help reduce emittance growth



Bob's scheme at Telluride shows recombination after final cooling

Layout



Recombination after 6D cooling

$\varepsilon_{TN} = 0.24$ mm (Bob's design at SLAC)
$\varepsilon_{LN} = 2.2$ mm

Norem matching (λ = Larmor wavelength, h = geometric curvature)

part 1	$L = \lambda / 2$	$\kappa = h / 2$
part 2	$L \approx 0.18\,\lambda$	$\kappa = h$
part 3	$L = \lambda / 2$	$\kappa = h / 2$

Assume
- upstream matching optics can adjust β_T
- upstream RF system can accelerate beams and adjust σ_Z
- want two beam pipes well separated going into 2nd bent solenoid

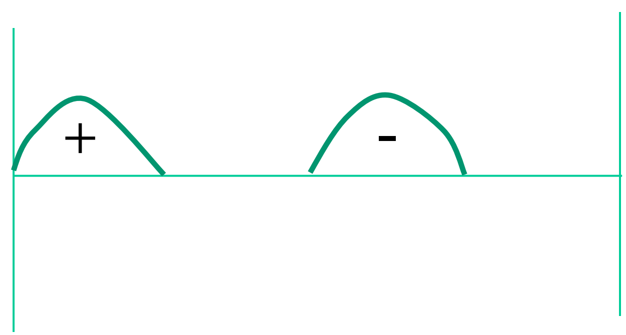
Maximum bunch length

- momentum spread is important design parameter
- want incident bunch length as long as possible
- want final positive & negative bunches separated in time by $\lambda_{RF}/2$

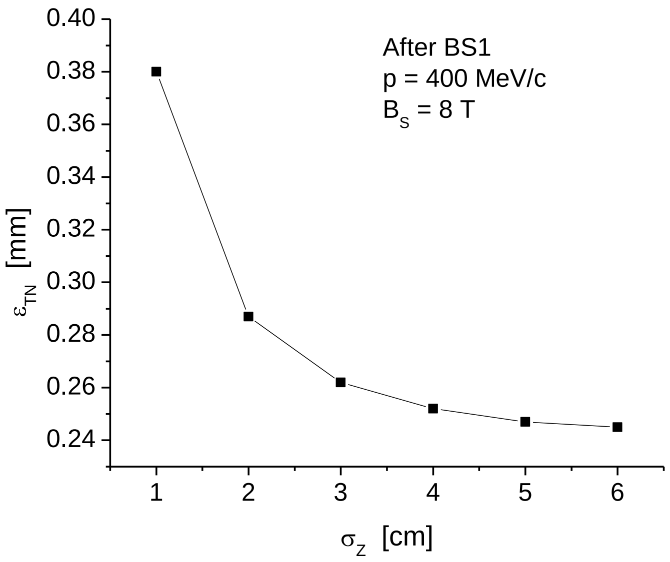
  where λ_{RF} is the wavelength of 1st RF system after recombination
- assume we can fit $\pm 3\sigma_Z$ into $\lambda_{RF}/4$

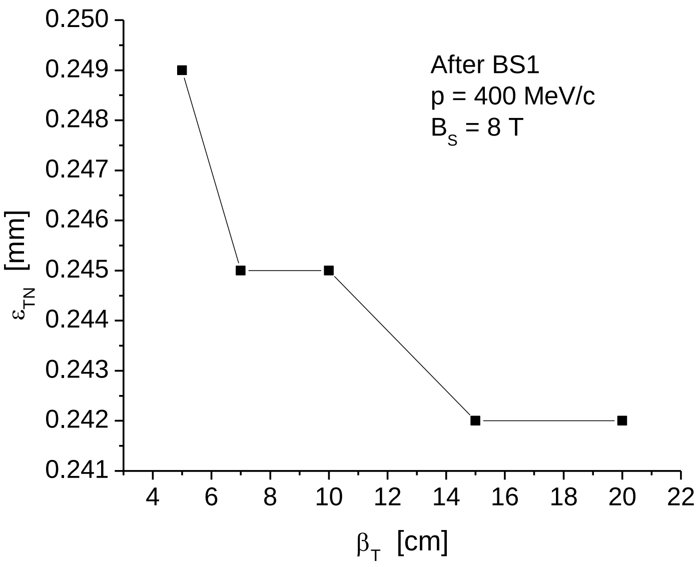
$$\mathbf{max}\ \boldsymbol{\sigma_Z = \lambda_{RF} / 24}$$

- first RF in final cooling here is 201 MHz, so λ_{RF} = 1.49 m
- max σ_Z = 6.2 cm

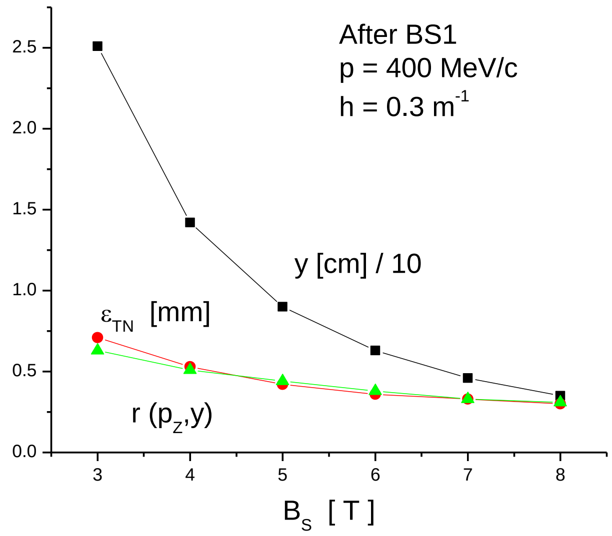


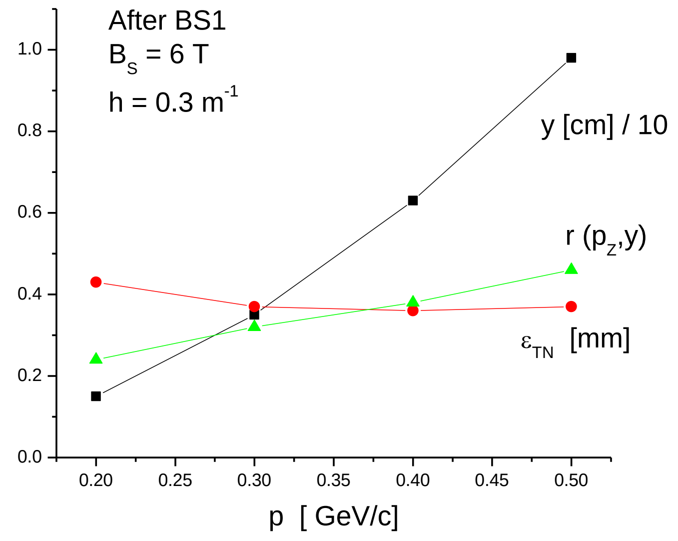
BS1 properties

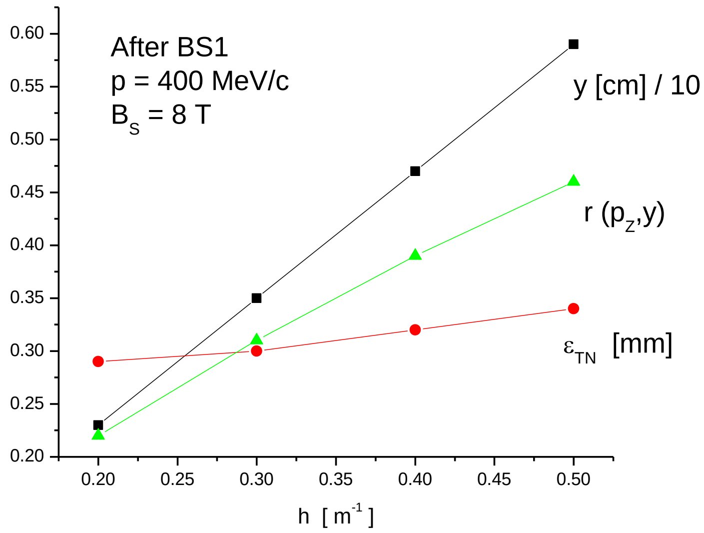




BS1 properties







- need large B_S and large p

Separation of incoming beam pipes

- bend angle thru each bent solenoid

$$\theta = \tfrac{1}{2}\lambda / 2\rho + L_C / \rho + \tfrac{1}{2}\lambda / 2\rho$$

- for this case with $L_C = 0.38\ \lambda$, $\theta = 0.24$ rad
- horizontal separation

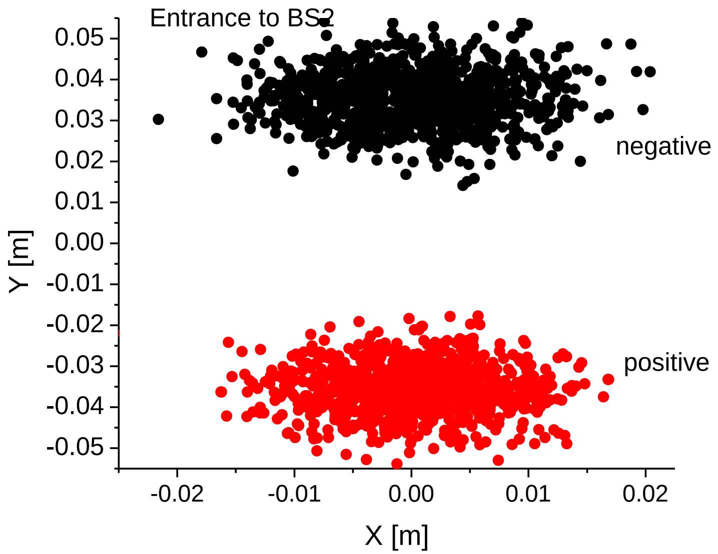
$$HS = L_T \sin\theta$$

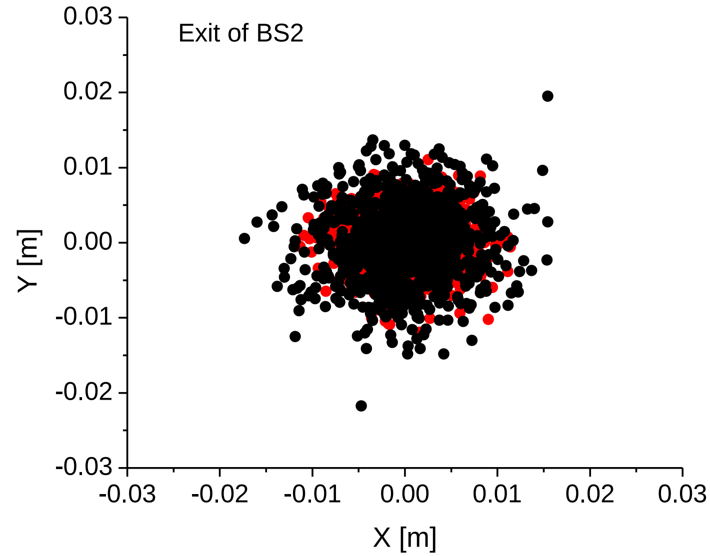
- for the case here with $L_T = 1.2$ m, HS = 29 cm
- this can be increased by increasing L_C or L_T or h
- How much separation do we need between the incoming beam lines?

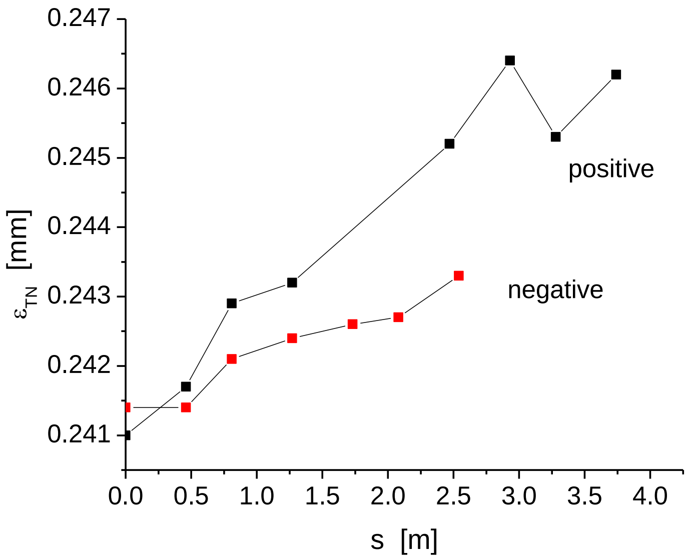
Parameters: after 6D

ε_{TN}	0.24	mm
ε_{LN}	2.2	mm
p	350	MeV/c
B_S	8	T
h	0.30	m^{-1}
Le	46	cm
Lc	35	cm
σ_Z	6	cm
β_T	13	cm
LT	1.2	m
HS	29	cm

Full channel: after 6D







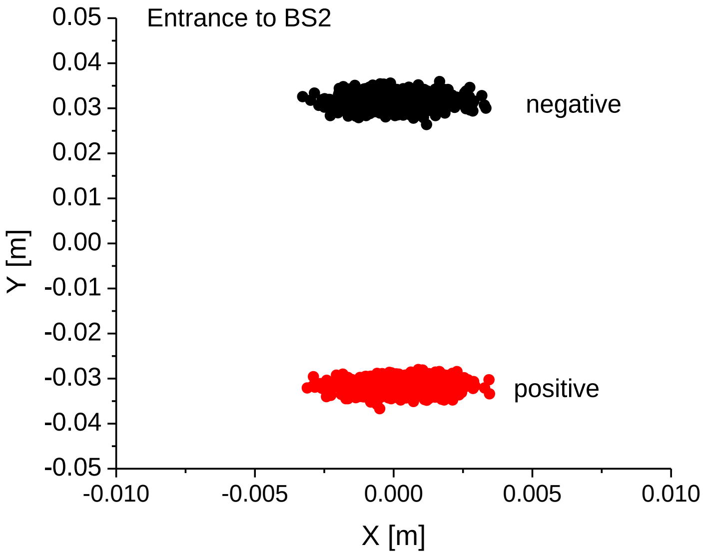
- transverse emittance growth small ~2%
- longitudinal emittance growth small ~1%
- transmission very good ~99%

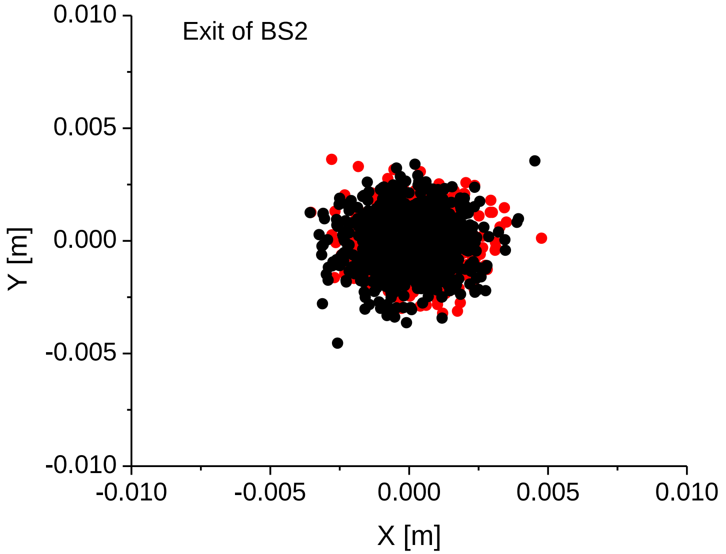
Parameters: after final

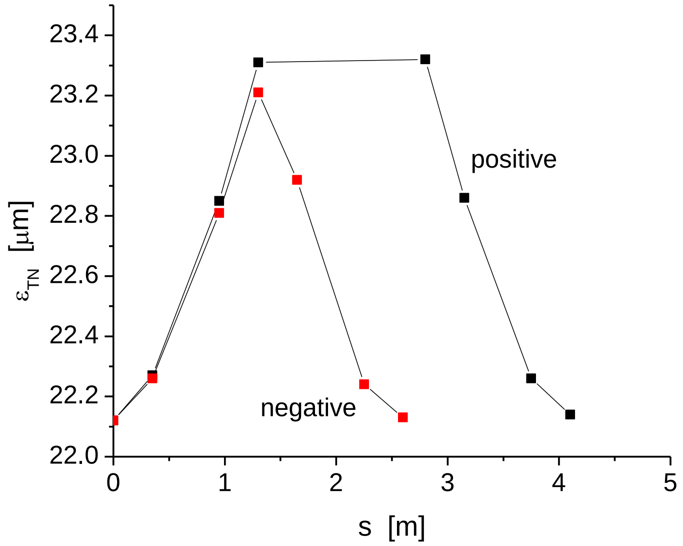
ε_{TN}	22	μm
ε_{LN}	~113	mm
p	400	MeV/c
B_S	12	T
h	0.30	m^{-1}
Le	35	cm
Lc	60	cm
σ_Z	300	cm
β_T	17	cm
LT	1.5	m
HS	42	cm

- σ_Z already at maximum for 4 MHz following RF

Full channel: after final

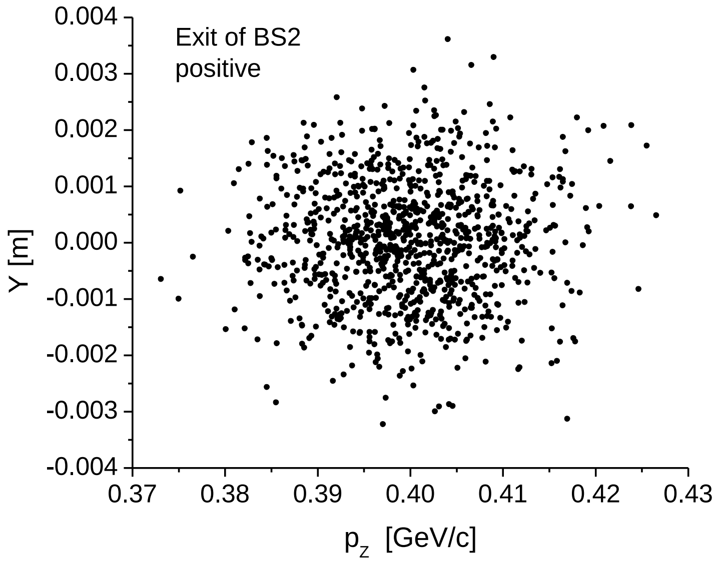


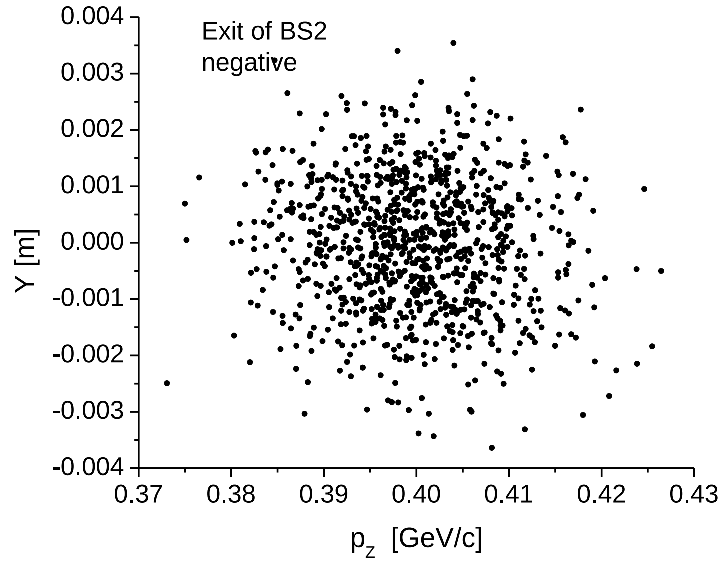




- transverse emittance growth small ~0.1%
- longitudinal emittance growth small ~4%
- transmission very good ~99%

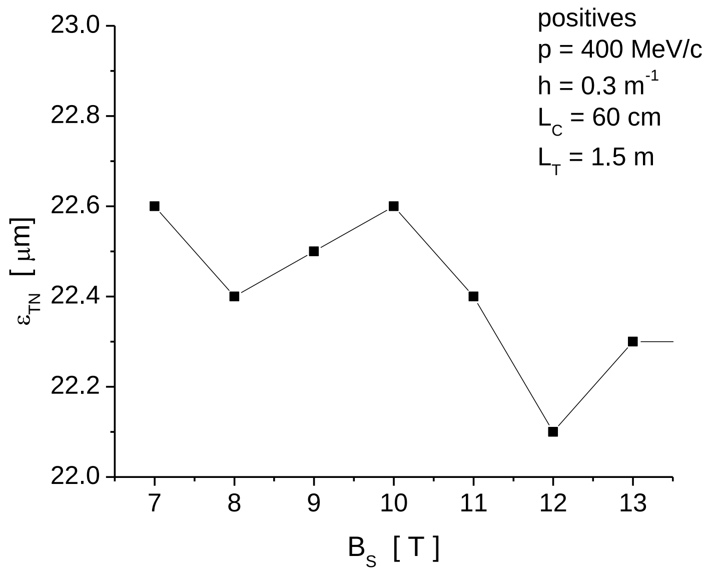
Full channel: after final





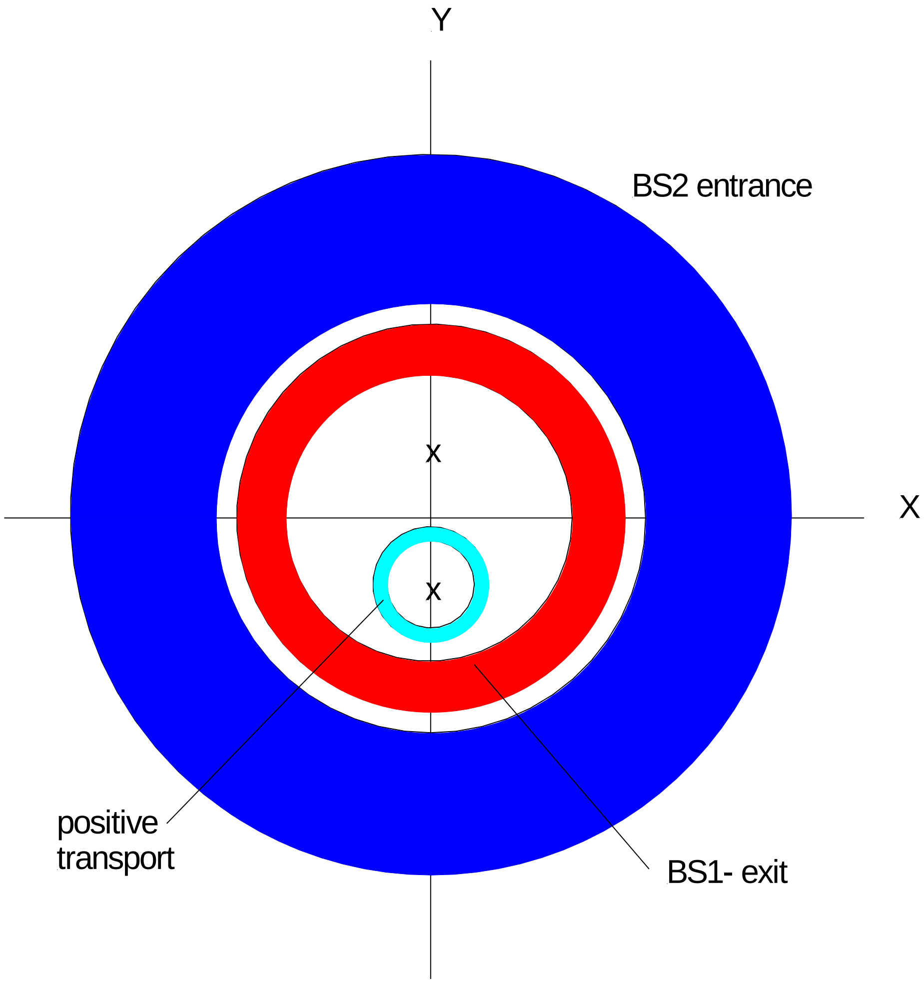
- dispersion completely removed

Can we use a lower field?



- how much emittance growth is acceptable?
- dropping down to 8 T increases ε_{TN} by ~1.5%

Entrance to BS2

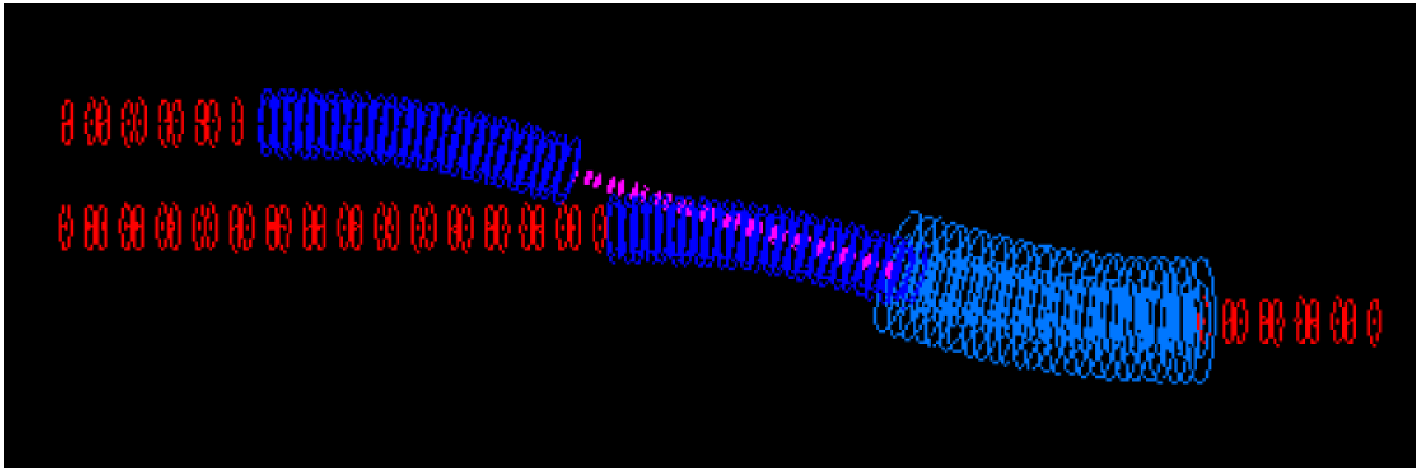


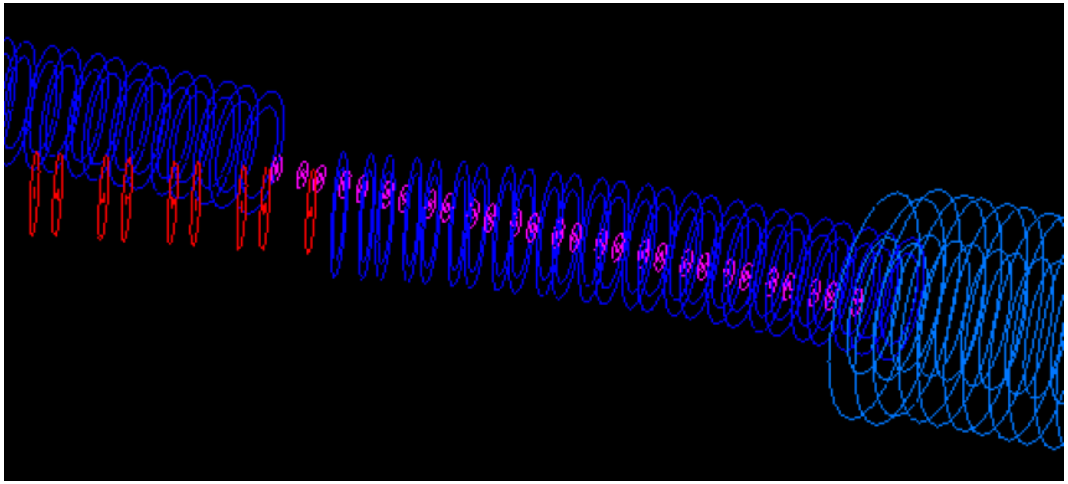
Three possible approaches

1. Equal deflection in BS1 and BS2 (here)
   - small dispersion & $\Delta\varepsilon$
   - external beam lines in a plane
   - complicated magnet design
   - susceptibility to fringe fields
2. Smaller deflection in BS1 than BS2
   - straightforward magnet design
   - external beam lines not in a plane
   - exit beam likely has dispersion & $\Delta\varepsilon$
3. Keep BS1 & BS2 symmetric, but add vertical deflections exiting BS1 and entering BS2; two transport lines
   - straightforward magnet design
   - external beam lines not in a plane
   - exit beam might have dispersion & $\Delta\varepsilon$

G4beamline model

- used ICOOL solution for initial layout and parameters





To do list (near term)

- improve G4beamline model with discrete coils
  - is a crossover coil design feasible?
  - try to adjust coil dimensions to allow one beam to pass thru gap in other beam
  - adjust current densities to get ~12 T on-axis
  - adjust coil positions to get ± reference particles to stay on-axis
  - check for additional emittance growth due to solenoid fringe fields

- look at ICOOL designs for the two alternatives
  - check expected dispersion and emittance growth

To do list (long term)

- get initial beam distribution from end of final cooling
- design acceleration up to 400 MeV/c
- design proper match into bent solenoids
- determine required horizontal separation of the two incoming beam lines
- determine maximum allowed transverse emittance growth
- adjust channel lengths so two charge bunches end up separated in time by ½ λ_{RF}