Optimized Target Parameters and Meson Production by IDS120h with Focused Gaussian Beam and Fixed Emittance (Update)

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Target Studies
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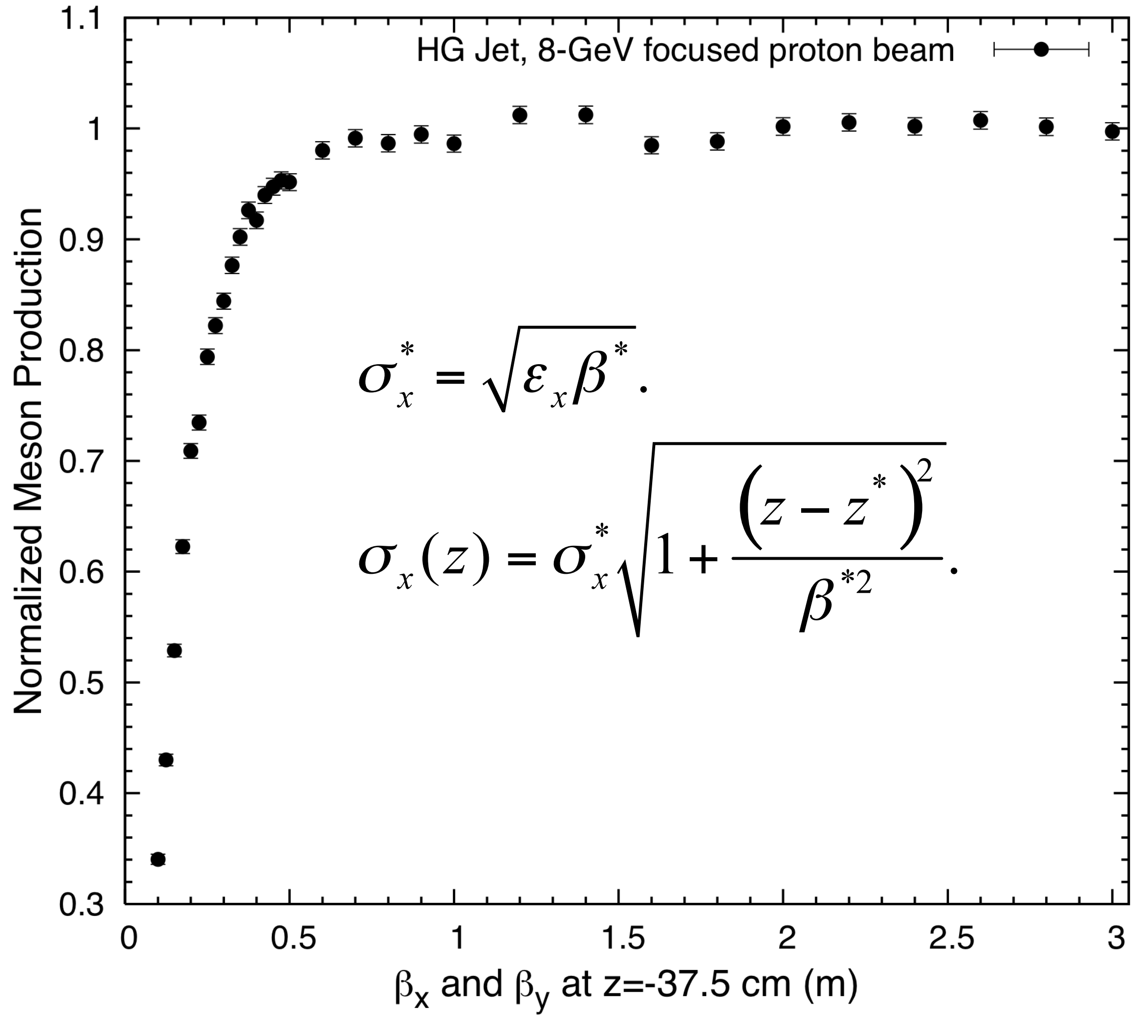
Focused Incident Proton Beam at 8 GeV

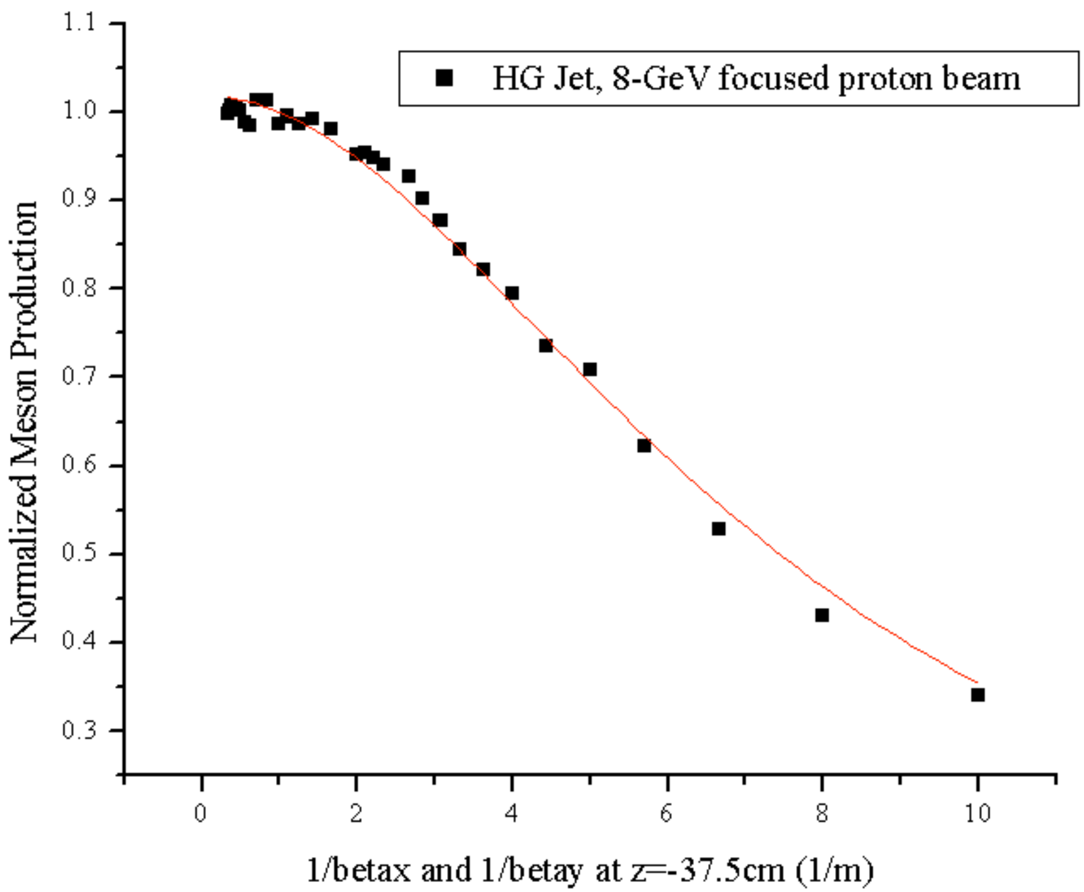
(Beam radius is fixed at 0.12 cm at z=-37.5 cm)



Relative normalized meson production is 0.84 of max at β* of 0.3 m for $\varepsilon_x = \varepsilon_y = 5\ \mu\text{m}$.

For low β* (tight focus) the beam is large at the beginning and end of the interaction region, and becomes larger than the target there.

Focused Incident Proton Beam at 8 GeV (Cont'd) (Beam radius is fixed at 0.12 cm at z=-37.5 cm)



Non-Linear Fit (Growth/sigmoidal, Hill)

$Y=N/(1+K2/beta^{-2})$
N=1.018
Sqrt(K2)=0.1368

Linear emittance is 5 µm with beam radius of 0.1212 cm and β* of 0.3 m.

Gaussian distribution (Probability density)

- In two dimensional phase space (u,v):

$$w(u,v) = \frac{1}{2\pi\sigma^2}\exp(-\frac{u^2+v^2}{2\sigma^2})$$

where u-transverse coordinate (either x or y),
$v = \alpha\, u + \beta\, u'$

α, β are the Courant-Snyder parameters at the given point along the reference trajectory.

In polar coordinates (r, θ):
$u = r\cos\theta \qquad v = r\sin\theta$
$u' = (v - \alpha\, u)/\beta = (r\sin\theta - \alpha\, u)/\beta$

Distribution function method

$$\theta = 2\pi\xi_1, \qquad \theta \in [0, 2\pi]$$

$$r = \sqrt{-2\sigma^2 \ln \xi_2}, \quad r \in [0, \infty]$$

Random number generator:

Θ = 2π*rndm(-1)
R = sqrt(-2*log(rndm(-1))*σ

Gaussian distribution
(Fraction of particles)

- The fraction of particles that have their motion contained in a circle of radius “a” (emittance $\varepsilon = \pi\, a^2/\beta$) is

$$F_{Gauss} = \int_0^a \frac{1}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} r dr = 1 - e^{-\frac{a^2}{2\sigma^2}}$$

Fraction of particles

$k=a/\sigma$	$\varepsilon_{K\sigma}$	F_{Gauss}
1	$\pi(\sigma)^2/\beta$	39.5%
2	$\pi(2\sigma)^2/\beta$	86.4%
2.5	$\pi(2.5\sigma)^2/\beta$ or $\sim 6\pi\sigma^2/\beta$	95.6%

Normalized emittance: $(\boldsymbol{\beta\gamma})\varepsilon_{K\sigma}$

Focused beam

- Intersection point (z=-37.5 cm):

  $\alpha^* = 0, \beta^*, \sigma^*$

- Launching point (z=-200 cm):

  L = 200-37.5 = 162.5 cm

  $\alpha = L/\beta^*$

  $\beta = \beta^* + L^2/\beta^*$

  $\sigma = \sigma^* \mathrm{sqrt}(1+L^2/\beta^{*2})$

These relations strictly true only for zero magnetic field.

Setting of simple Gaussian distribution

- INIT card in MARS.INP (MARS code)

INIT XINI YINI ZINI DXIN DYIN DZIN WINIT

XINI = x0 DXIN = dcx0

YINI = y0 DYIN = dcy0

ZINI = z0 DZIN = dcz0 = $\mathrm{sqrt}(1\text{-}dcx0^2\text{-}dcy0^2)$

(Initial starting point and direction cosines of the incident beam)

Setting with focused beam trajectories

- Modeled by the user subroutine BEG1 in m1510.f of MARS code

x_v or x_h (transverse coordinate: u);

x'_v or x'_h (deflection angle: u')

$XINI = x_0 + x_h$ $DXIN = dcx_0 + x'_h$

$YINI = y_0 + x_v$ $DYIN = dcy_0 + x'_v$

$ZINI = z_0$ $DZIN = sqrt(1-DXIN^2-DYIN^2)$

Optimization of target parameters

- Fixed beam emittance ($\varepsilon_{K\sigma}$) to $\pi\,(\sigma)^2/\beta$
- Optimization method in each cycle

(Vary beam radius or beam radius σ^*, while vary the β^* at the same time to fix the beam emittance; Vary beam/jet crossing angle; Rotate beam and jet at the same time)

We also optimized the beam radius and target radius separately (not fixed to each other).

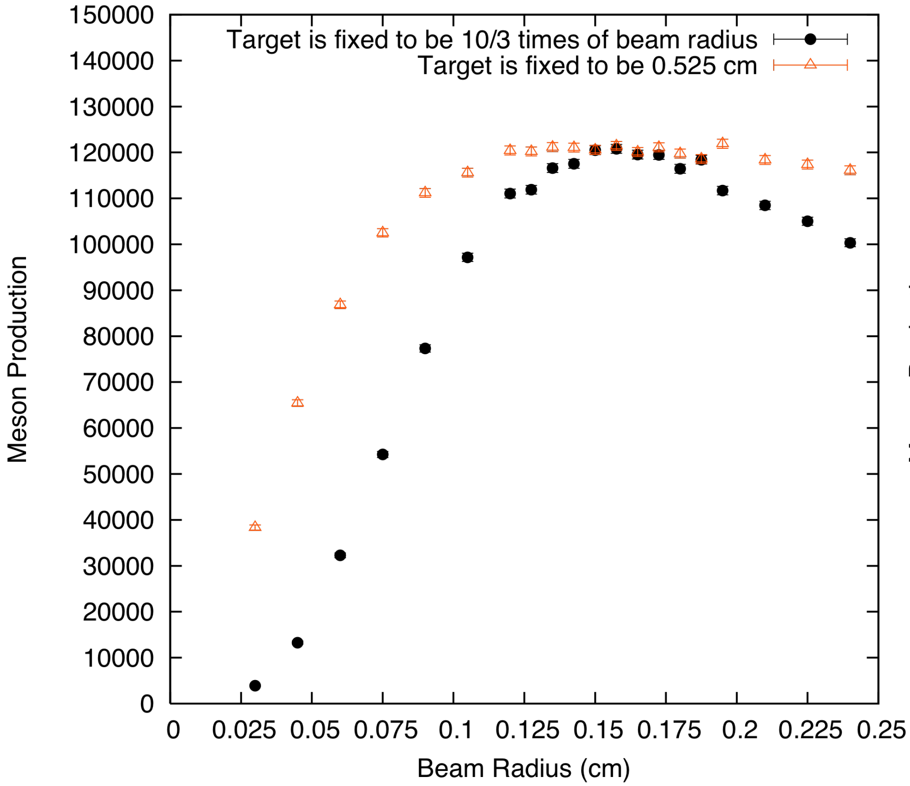
Optimized Target Parameters and Meson Productions at 8 GeV

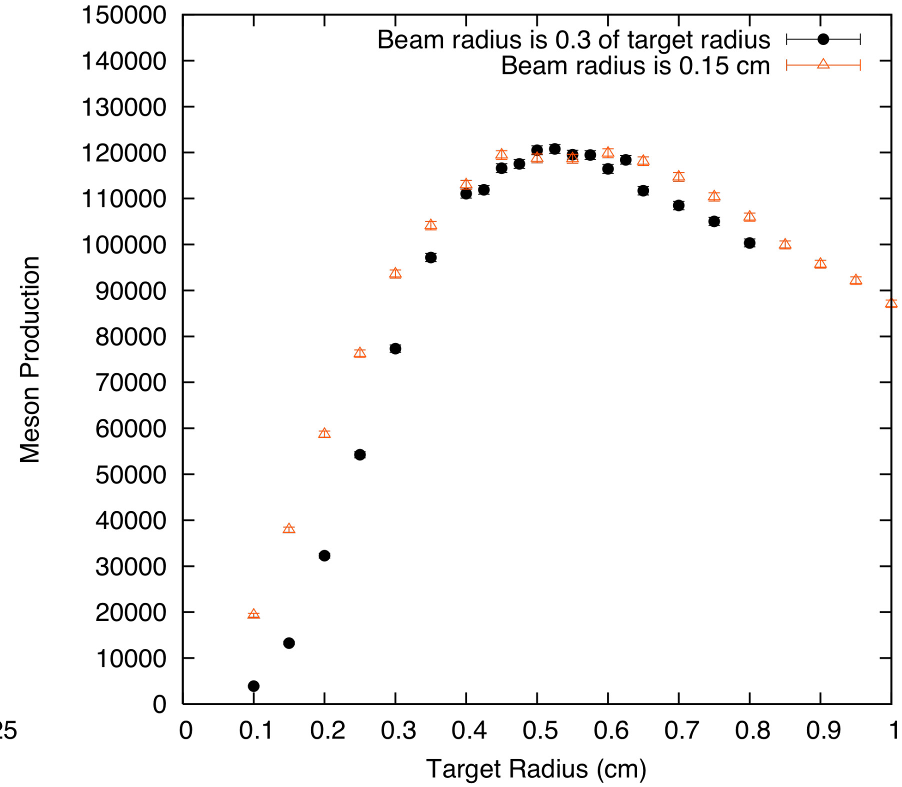
(Linear emittance is fixed to be 4.9 µm)

	Radius (cm)	Beam/jet crossing angle (mrad)	Beam angle/Jet angle (mrad)
Initial	0.404 (target)	20.6	117/137.6
1st Run	0.525 (target)	25	120/145
Old 2nd Run (vary target radius and beam radius is fixed to be 0.3 of target radius)	0.544 (target)	25.4	120/145.4
New 2nd Run (vary beam radius with fixed target radius of 0.525 cm; vary target radius with fixed beam radius of 0.15 cm.)	Beam radius: 0.15 Target radius: 0.548	26.5	127/153.5

Optimize beam radius and target radius separately

(Linear emittance is fixed to be 4.9 µm)





We found almost no improvement in optimized meson production if the beam radius is not fixed at 30% of target radius and optimized separately!

Optimized Meson Productions at 8 GeV

(Linear emittance is fixed to be 5 μm)

Gaussian Distribution	Meson Production
Simple (0.404cm/20.6mrad/117mrad)	32563
Focused beam (0.404cm/20.6mrad/117mrad)	27489 (-15.6% less than Simple)
Focused beam with fixed Emittance at 5 μm (0.544cm/25.4mrad/120mrad)	30025 (-8.9% less than Simple) (8.4% more than Focused beam)
Focused beam with fixed Emittance at 5 μm (0.15 cm (beam)/0.54cm(target)/ 26.5mrad(crossing)/127mrad(beam)	30187

Optimized Target Parameters and Meson Productions at 8 GeV

(Linear emittance is fixed to be 10 μm)

	Beam Radius (cm)	Target Radius (cm)	Beam/jet crossing angle (mrad)	Jet angle (mrad)
Initial	0.404*0.3	0.404	20.6	137.6
1st Run	0.2325	0.60	29	153
2nd Run	0.2325	0.65	32	167

Gaussian Distribution	Meson Production
Focused beam with fixed Emittance at 10 μm (0.2325 cm (beam)/0.65cm(target)/ 32mrad(crossing)/135mrad(beam)	27641 (-16% less than Simple)

Angular Momentum Issue

Step 1 (w/t angular momentum):

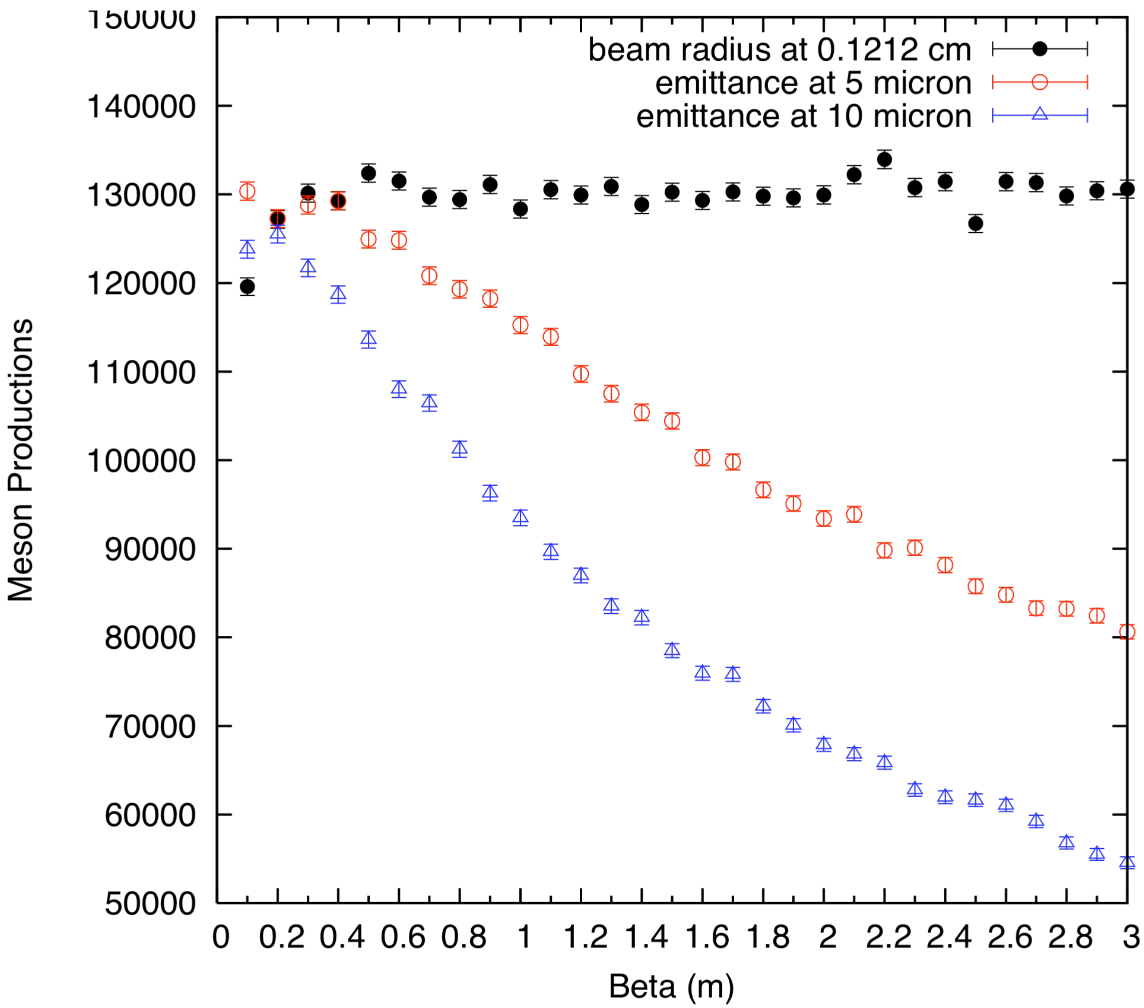
- Create a beam (simple Gaussian or focused) with target radius of 0.404 cm, beam angle of 117 mrad and jet angle of 137.6 mrad at z=-37.5 cm.
- Track back the beam to z=-200 cm under the SC field and no HG Jet.
- Based on the backward beam at z=-200 cm, create the forward beam at z=-200 cm.
- Read the forward beam and run MARS15.

Angular Momentum Issue (Cont'd)

- Meson production is 1.30141*10^5.

(Old Method with single centroid particle track back and using Twiss formulae at z=-200 cm w/t SOL field, Meson production is 1.09957*10^5.)

Meson Productions



Formulae Related with Angular Momentum

$q=1.6\times10^{-19}$ (C), $c = 3\times10^{8}$ (m/s)

1 (GeV) = $(10^{9}\times1.6\times10^{-19})$ (J) = $(10^{9}\times q)$ (J)

1 (J) $=1/(10^{9}\times q)$ (GeV)

$\Delta Px= qBcy/2$ (J)

$\Delta Py= -qBcx/2$ (J)

$\Delta Px=Bcy/(2\times10^{9})$ (GeV)

$\Delta Py=-Bcx/(2\times10^{9})$ (GeV)

Estimation of Angular Momentum Effect

- Proton Beam:

  E0=0.938272 GeV

  KE=8 GeV

  ET=8.9382 GeV

  $P=(ET^2-E0^2)^{1/2}=8.8888$ GeV

- (x0,y0,Px,Py), without angular momentum

  (x0,y0,Px+ΔPx,Py+ΔPy), with angular momentum

Estimation of Angular Momentum Effect (Cont'd)

- Z = -300 cm, B ~ 5.68 T

  x0 ~ -8.002 cm = -0.08 m

  y0~16.617 cm = 0.16617 m
- $\Delta Px \sim 5.68\times3\times10^{8}\times(0.16617)/(2\times10^{9}) \sim 0.142$ (GeV)

  $\Delta Py \sim -5.68\times3\times10^{8}\times(-0.08)/(2\times10^{9}) \sim 0.068$ (GeV)
- $Pz = (P^2-(Px+\Delta Px)^2-(Py+\Delta Py)^2)^{1/2}$

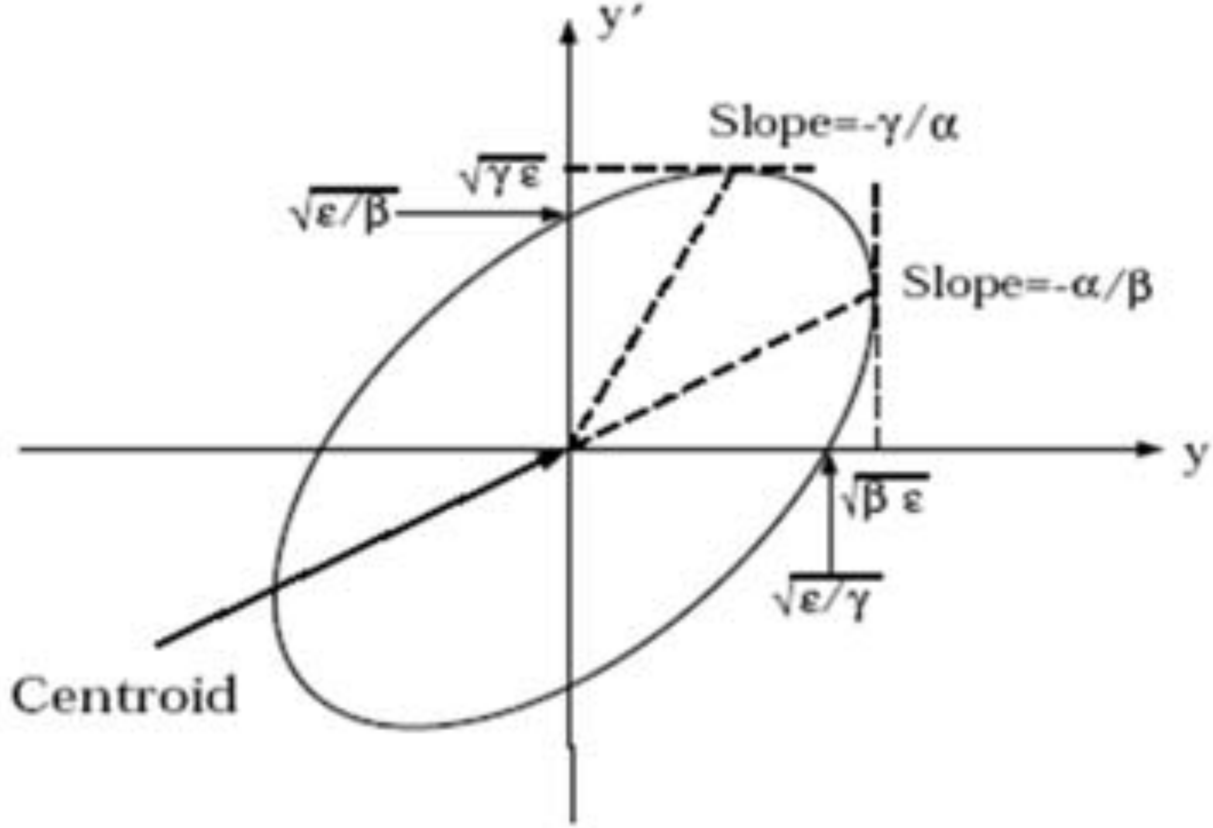
Angular Momentum Issue

Step 2 (simulation with angular momentum):

(Under way)

BackUp

Courant-Snyder Invariant



Emittance (rms) and Twiss Parameters

$$\varepsilon_{rms,x} = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2}$$

$$\alpha_x = -\frac{\langle xx' \rangle}{\varepsilon_{rms,x}}$$

$$\beta_x = \frac{\langle x^2 \rangle}{\varepsilon_{rms,x}}$$

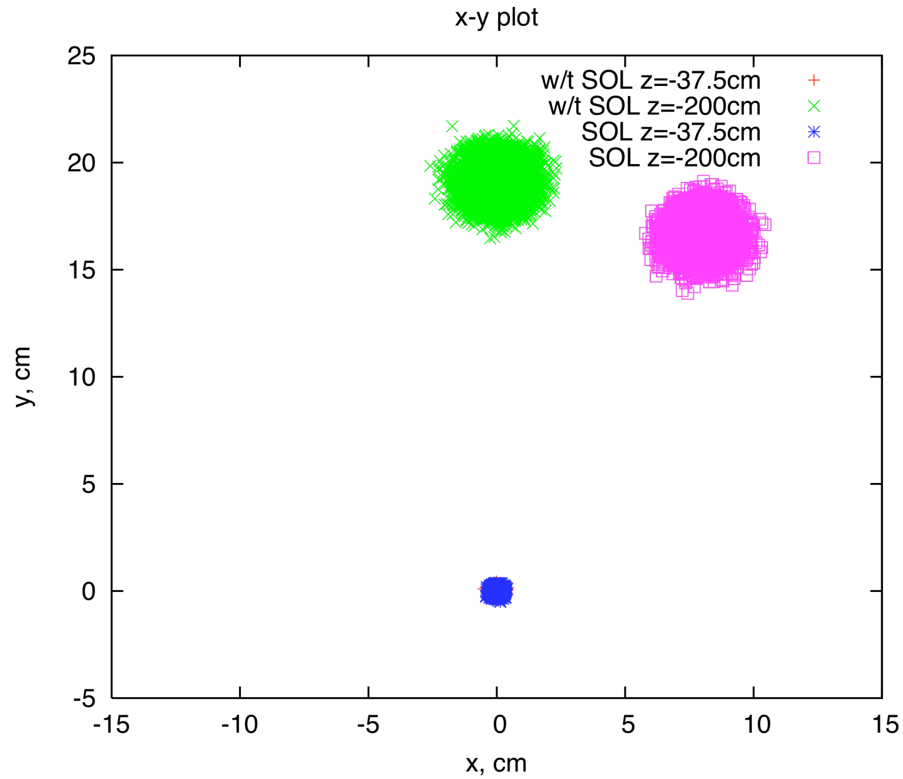
$$\gamma_x = \frac{\langle x'^2 \rangle}{\varepsilon_{rms,x}}$$

$$\beta_x \gamma_x - \alpha_x^2 = 1$$

Effect of Solenoid Field

[Backtrack particles from z = -37.5 cm to z = - 200 cm.]

(Could then do calculation of α, β, σ at z = -200 cm, but didn't)



Effect of Solenoid Field