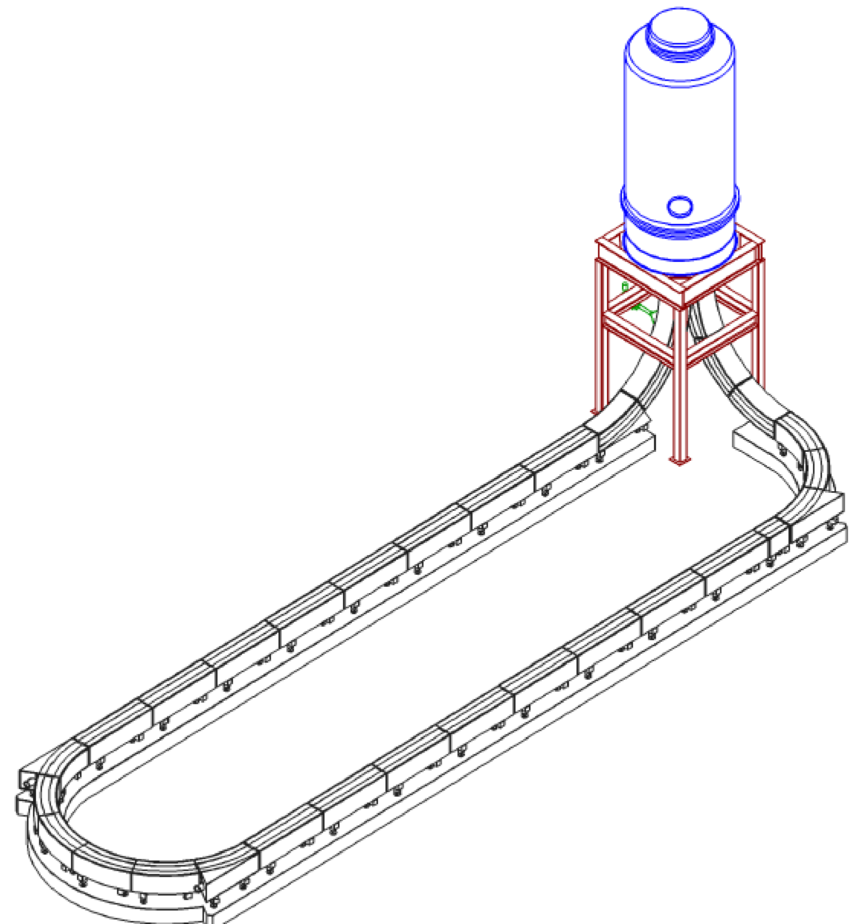
# Calculations on high-energy electron cooling in the HESR

D. Reistad, B. Gålnander, K. Rathsman
TSL, Uppsala

A. Sidorin
JINR, Dubna

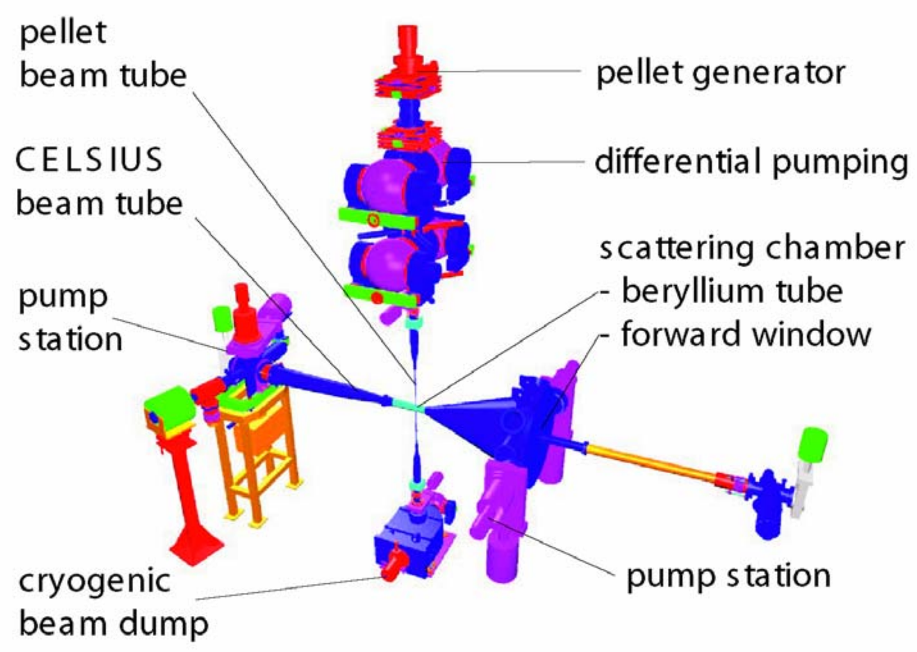


PANDA requires luminosity of $2\times10^{31} - 2\times10^{32}$ cm$^{-2}$s$^{-1}$ in $\bar{p}p$ collisions

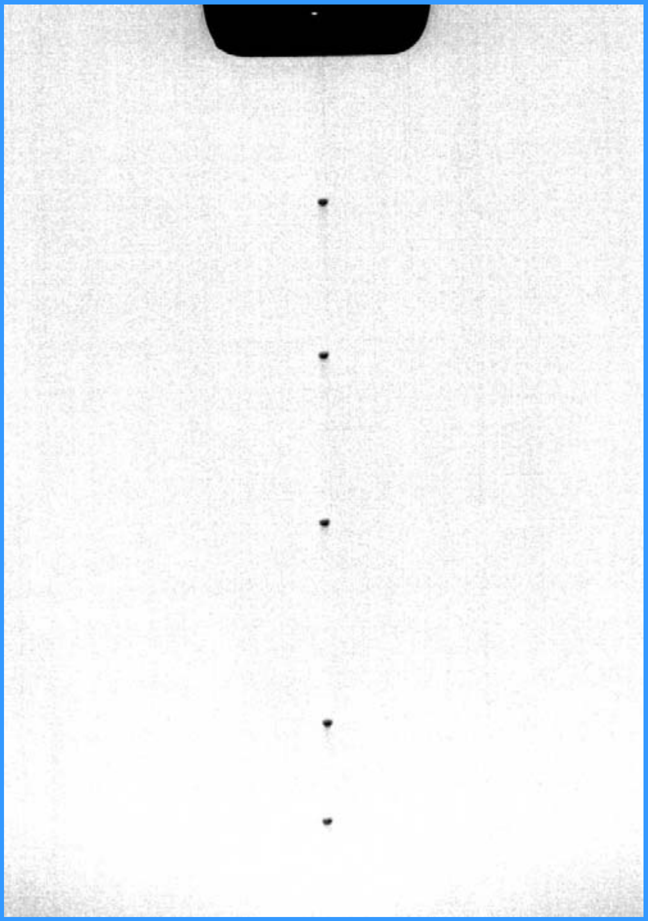
with $10^{10} - 10^{11}$ stored antiprotons

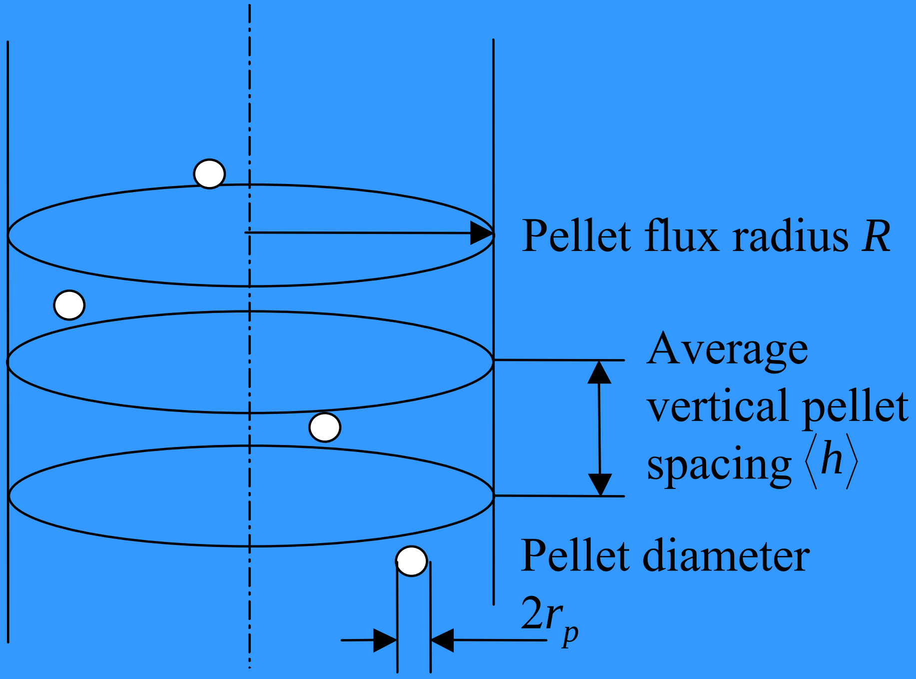
This requires internal target thickness $4\times10^{15}$ cm$^{-2}$

Only known internal target which meets this requirement is hydrogen pellet target:




# Hydrogen pellet target






Pellet flux diameter can be varied by choice of a "skimmer" between 1.5 and 3 mm. We decided to do present computations with $\underline{2R = 3\text{ mm}}$

Target thickness $4\times10^{15}$ cm$^{-2}$ is achieved if $\langle h \rangle = 4\text{ mm}$

This corresponds to 15,000 pellets/s

$2r_p = 30\,\mu\text{m}$

# CHOICE OF BEAM SIZE AT TARGET

$$\rho_{\text{eff,mean}} = \frac{\langle \Re \rangle}{\sqrt{2\pi}\sigma_x} \int_{-R}^{R} 2\sqrt{R^2 - x^2} \exp\left(-\frac{x^2}{2\sigma_x^2}\right) dx$$

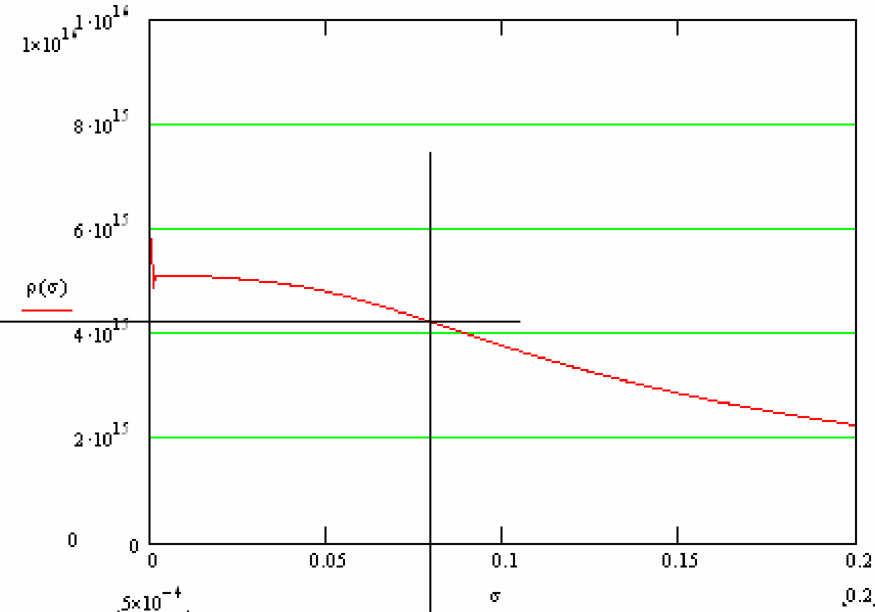
where

$$\langle \Re \rangle = \frac{\frac{4}{3}\pi r_p^3}{\pi R^2 \langle h \rangle} \Re; \quad \Re = 4.3 \times 10^{22}$$

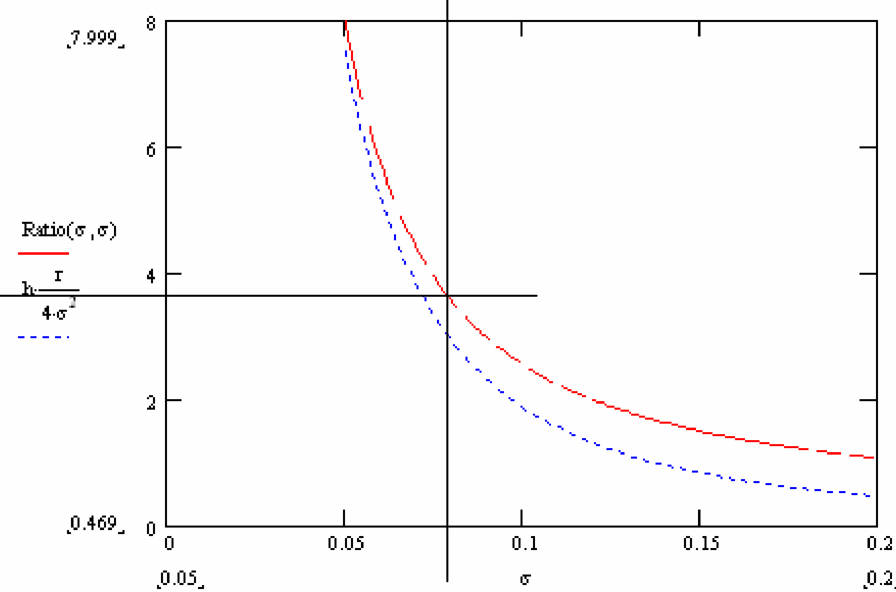
$$\rho_{\text{eff, max}} = \frac{\Re}{2\pi\sigma_x\sigma_y} \int_{-r_p}^{r_p} \int_{-\sqrt{r_p^2-x^2}}^{\sqrt{r_p^2-x^2}} 2\sqrt{r_p^2 - x^2 - y^2} \times$$

$$\times \exp\left(-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}\right) dy dx$$

80 %




3.5




0.8 mm

# CHOICE OF BETA AT TARGET

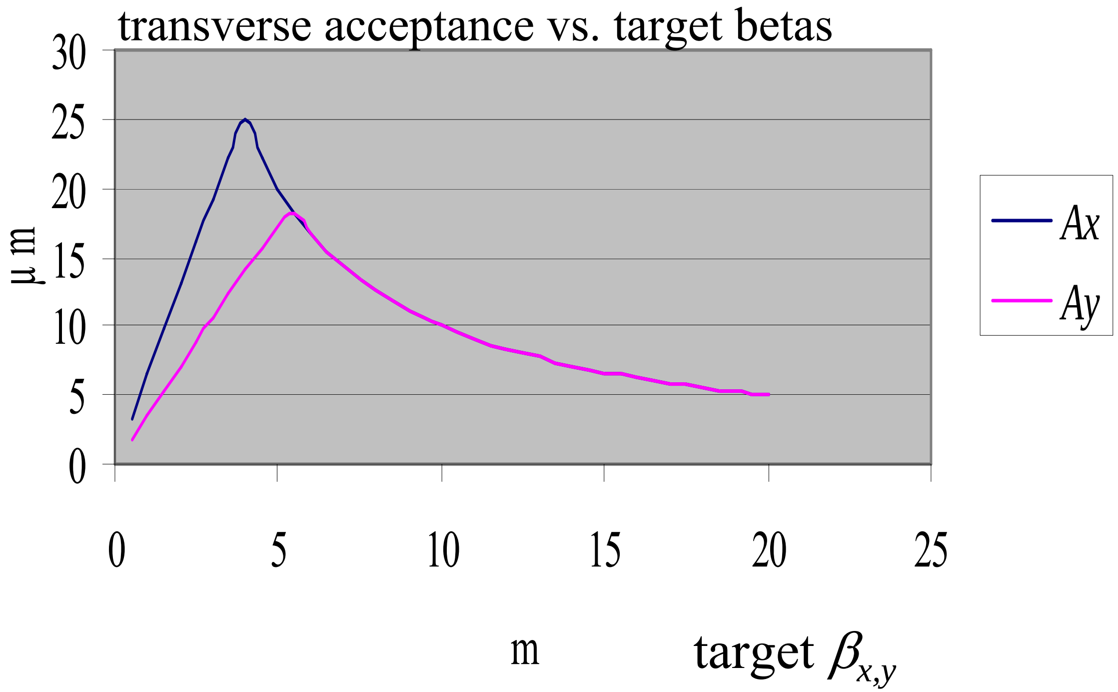
$$\sigma_{\text{single scattering}} = \pi \left( \frac{2 r_e m_e c^2}{c p \beta} \right)^2 \cdot \frac{\beta_T}{A}$$

$$A_x = \min\left( \frac{(44.5\text{ mm})^2}{\beta_{x,\max}}, \frac{(10\text{ mm})}{\beta_{x,T}} \right)$$

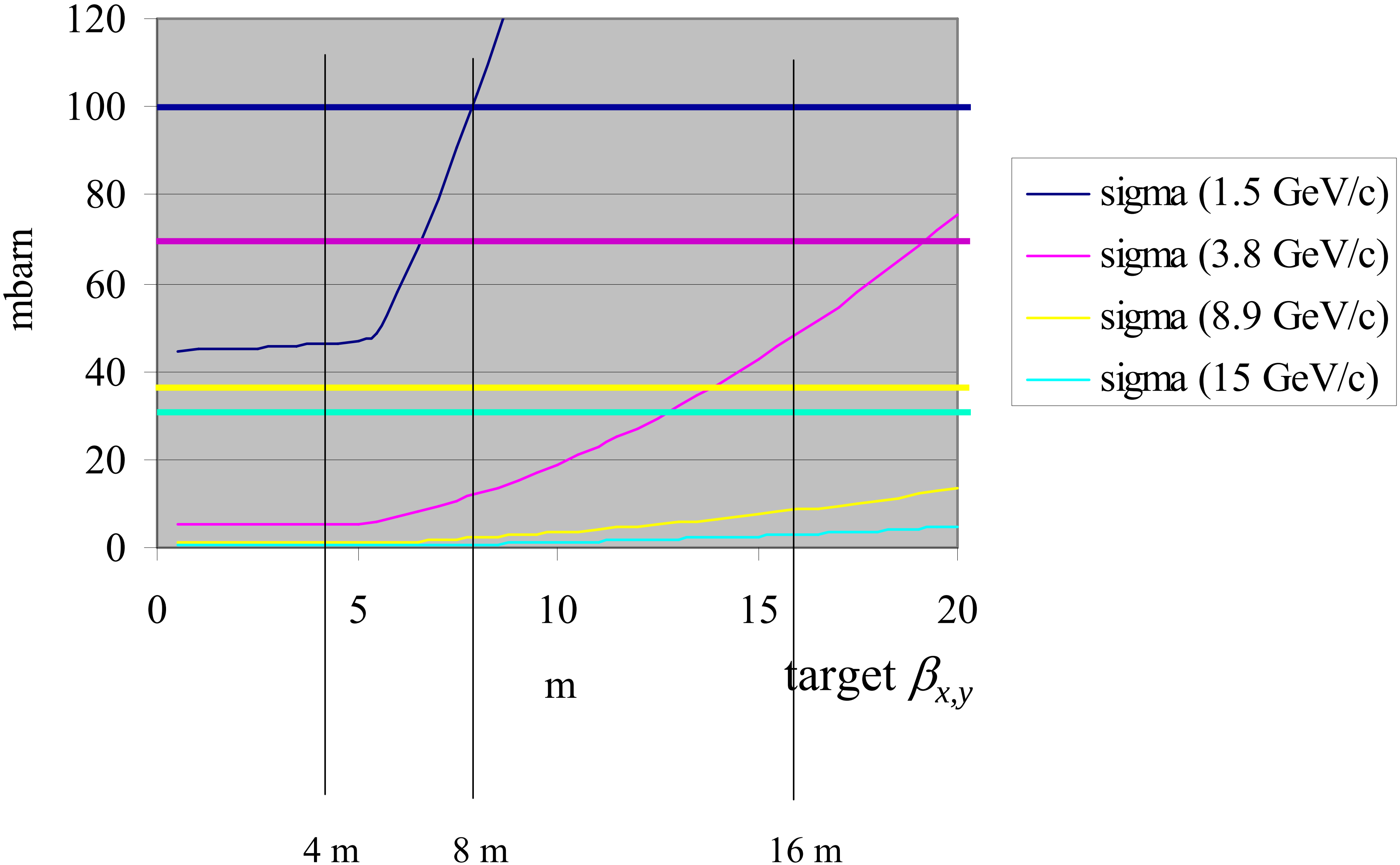
$$A_y = \min\left( \frac{(44.5\text{ mm})^2}{\beta_{y,\max}}, \frac{(10\text{ mm})}{\beta_{y,T}} \right)$$

$$\beta_{x,\max} = \beta_{x,T} + \frac{300\text{ m}^2}{\beta_{x,T}}$$

$$\beta_{y,\max} = \beta_{y,T} + \frac{550\text{ m}^2}{\beta_{y,T}}$$



# CHOICE OF BETA AT TARGET

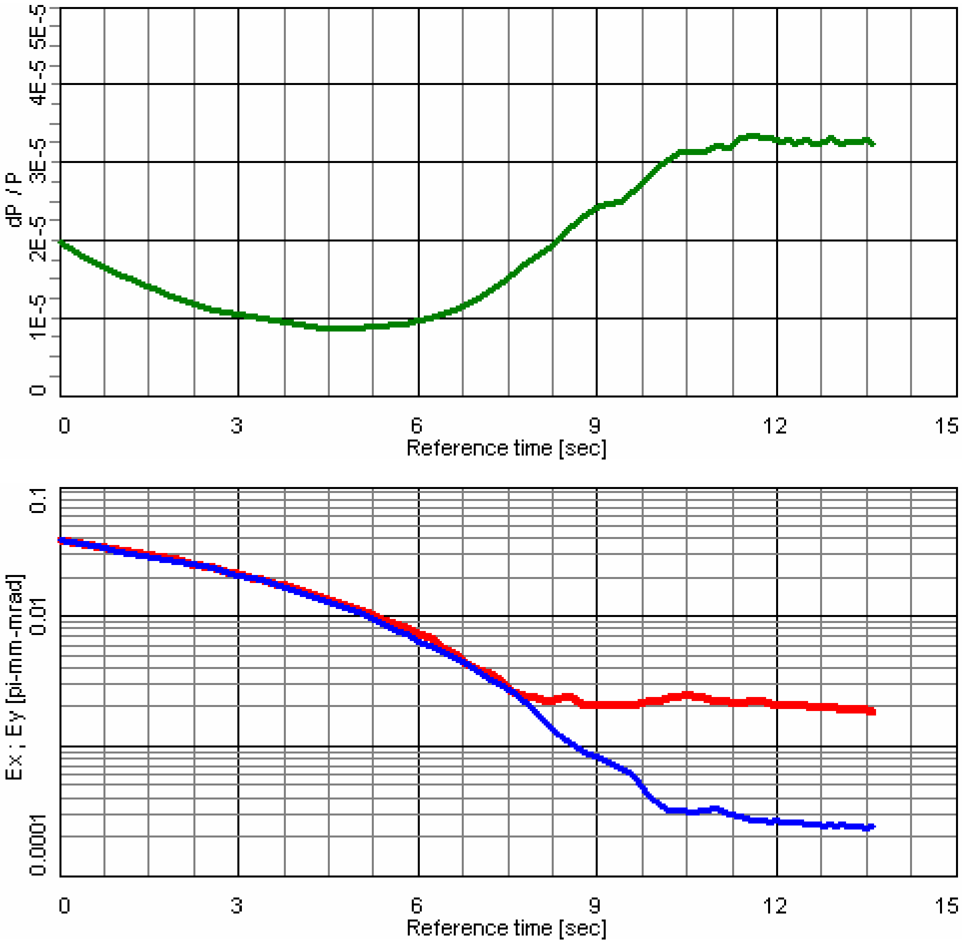


## TRANSVERSE EMITTANCE

$$\frac{(0.8\,\mathrm{mm})^2}{\beta_{\mathrm{target}}} = \begin{cases} 0.16\,\mu\mathrm{m} & (1.5\ \mathrm{GeV}/c) \\ 0.08\,\mu\mathrm{m} & (3.8\text{-}8.9\ \mathrm{GeV}/c) \\ 0.04\,\mu\mathrm{m} & (15\ \mathrm{GeV}/c) \end{cases}$$

| | |
|---|---|
| effective length of electron cooler | 20 m |
| electron current | 1 A (0.2 A @ 1.5 GeV/c) |
| electron beam radius, uniform cylinder | 5 mm |
| magnetic field in electron cooler | 0.2 T |
| beta value at electron cooler (both H and V) | 80 m (40, 160 m @ 1.5, 15 GeV/c) |
| transverse electron temperature (in centre of electron beam) | 1 eV |
| Transverse gradient of electron velocity (in order to take envelope oscillations into account. The chosen value corresponds to a cyclotron radius of 0.1 mm, or 35 eV, at the edge of the electron beam) | $7\times10^{-8}$ $s^{-1}$ |
| longitudinal electron temperature | 0.5 meV |
| electron beam neutralization | nil |
| cooling force model | Parkhomchuk |
| rms. straightness of magnetic field lines | $1\times10^{-5}$ |
| hydrogen pellet target, pellet size | 30 µm |
| pellet stream diameter | 3 mm |
| vertical separation between pellets | 4 mm |
| beta value (both planes) at target | 8 m (4 , 16 m @ 1.5, 15 GeV/c) |
| nuclear reaction cross section | 100, 70, 55, 50 mbarn @ 1.5 3.8,8.9, 15 GeV/c) |
| intra-beam scattering | Martini model |
| barrier bucket voltage | 200 V |
| barrier duration (relative to circumference) | 10 % |

# (NEED FOR) EMITTANCE STABILIZATION



# EMITTANCE STABILIZATION

Experience from existing electron coolers is that it is easy to not align perfectly and get broad transverse distributions.

Experience is also that it is much more critical to align correctly to get small transverse beam than to get small $\Delta p/p$

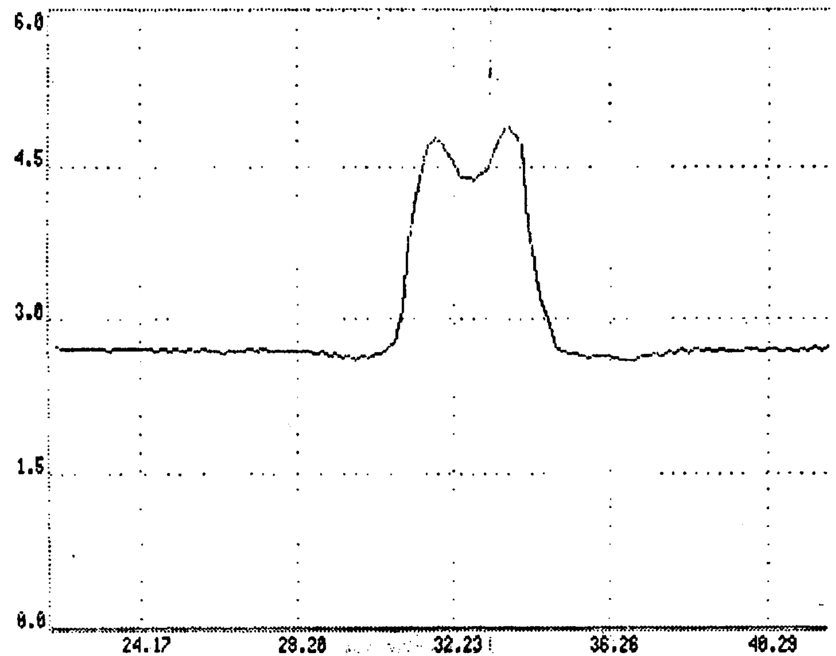
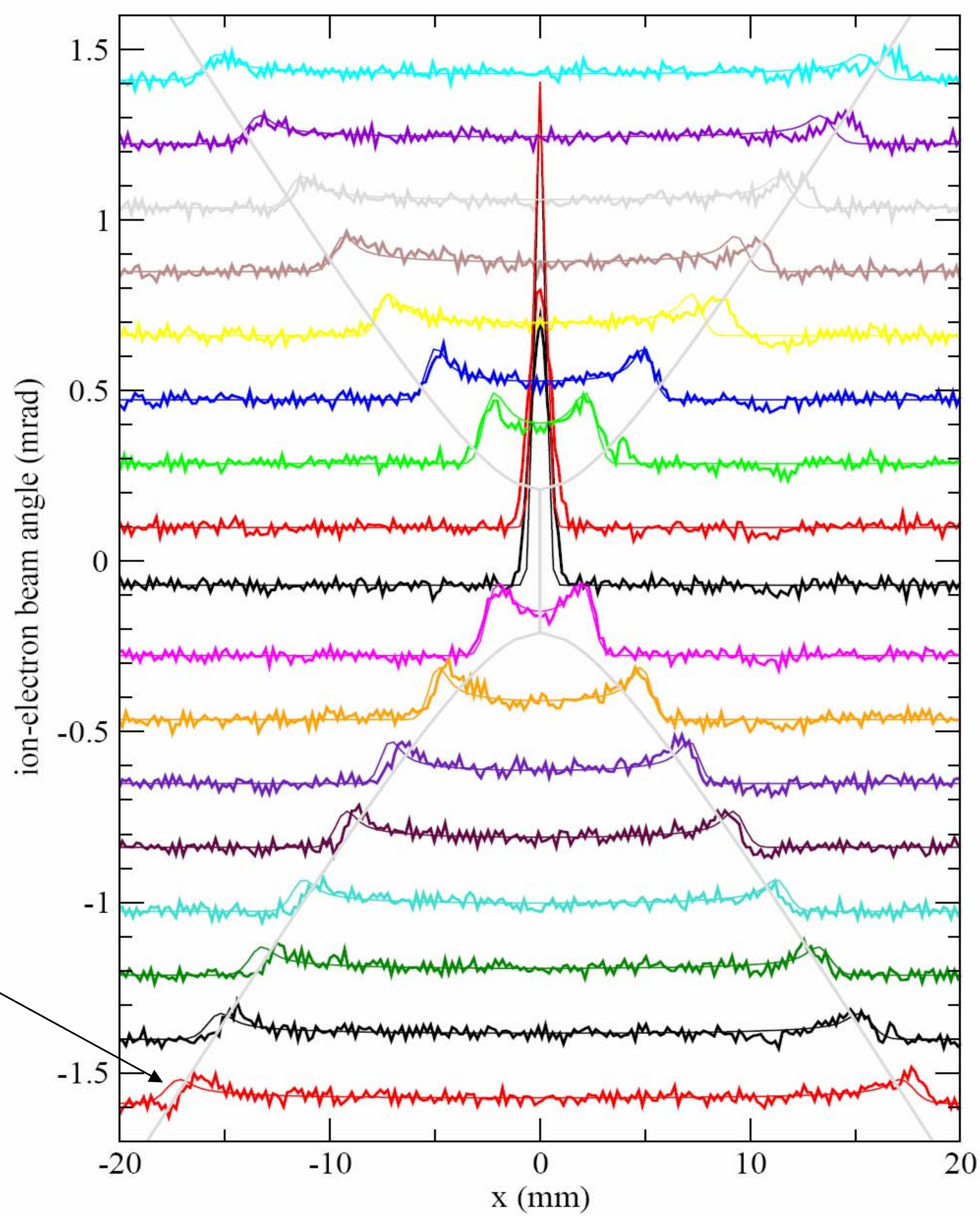



Figure 1: A double peak horizontal beam profile for 250 MeV/u $O^{8+}$. The scale on the $x$-axis is in mm.

Effect of misalignment between electron beam and ion beam in CELSIUS: electron-cooled 200 MeV/*u* $Ar^{18+}$.

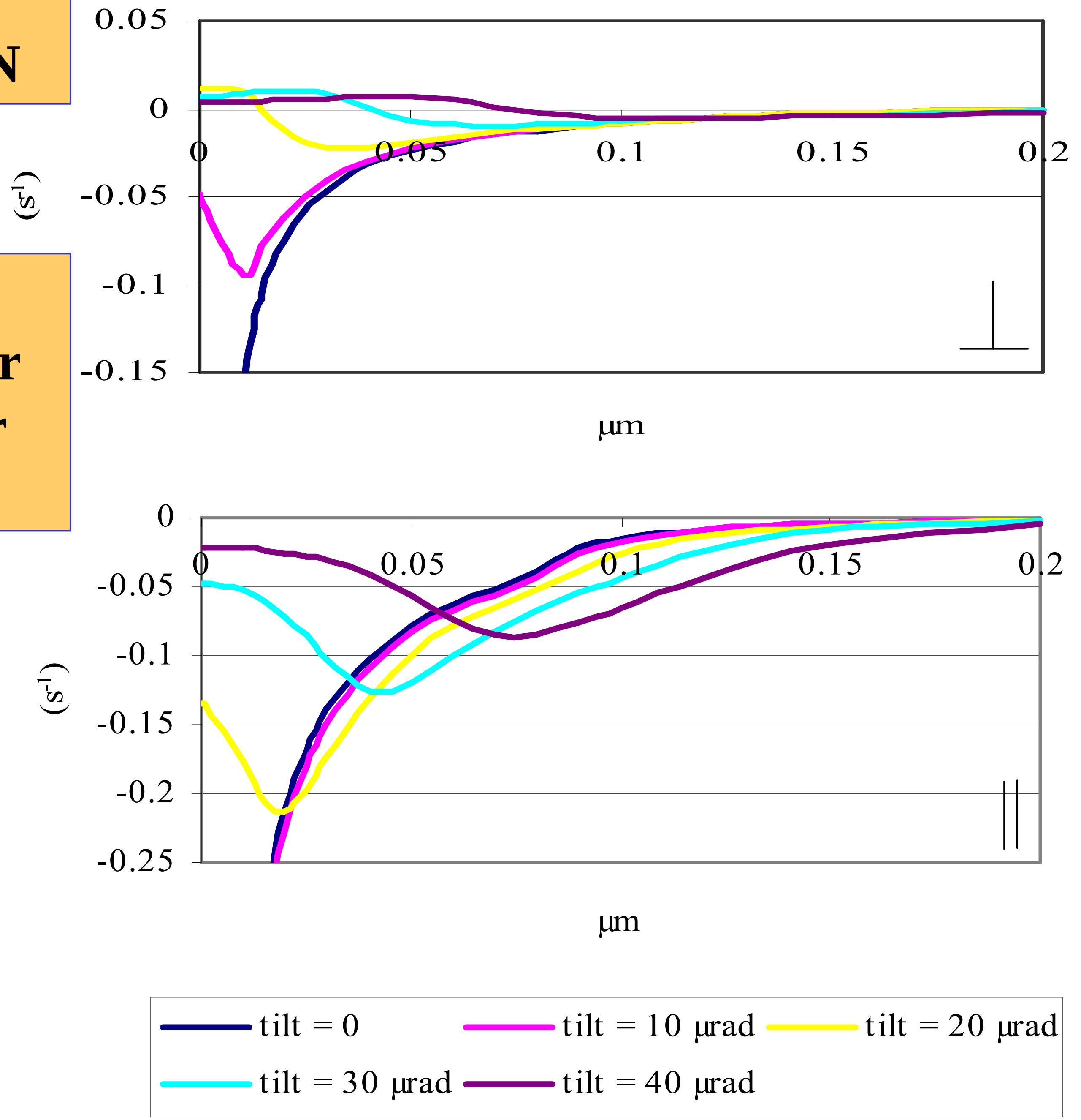
measured with magnesium-jet beam profile monitor

Curves represent theoretical profiles (if constant diffusion rate)

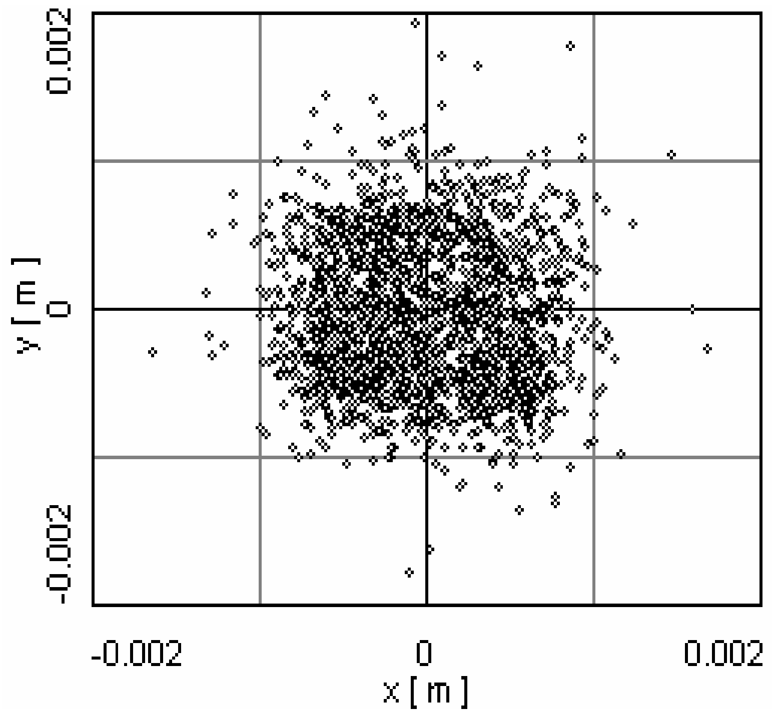


# EMITTANCE STABILIZATION

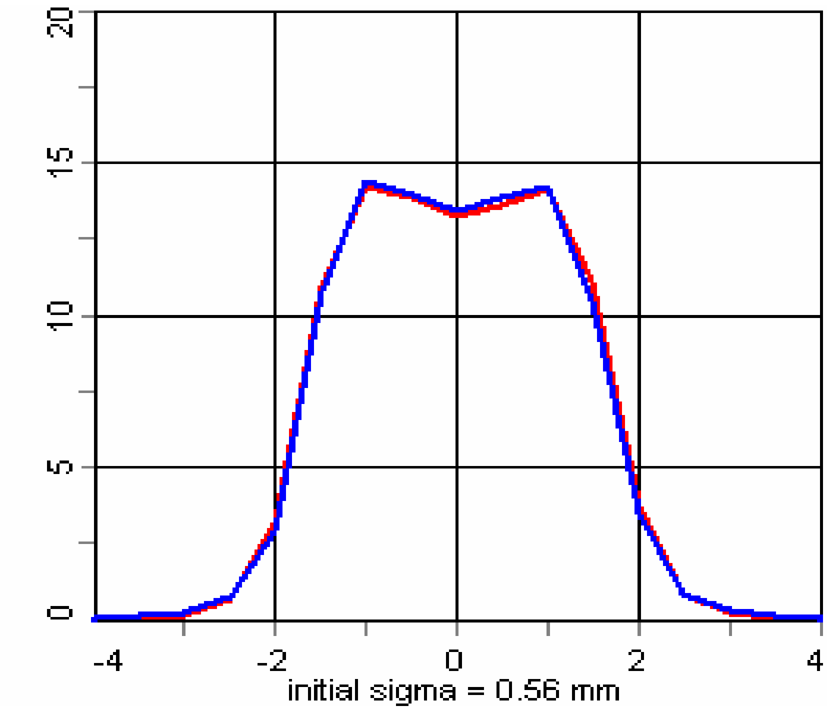
# Transverse and longitudinal cooler rates @ 8 GeV for different tilts



# EMITTANCE STABILIZATION



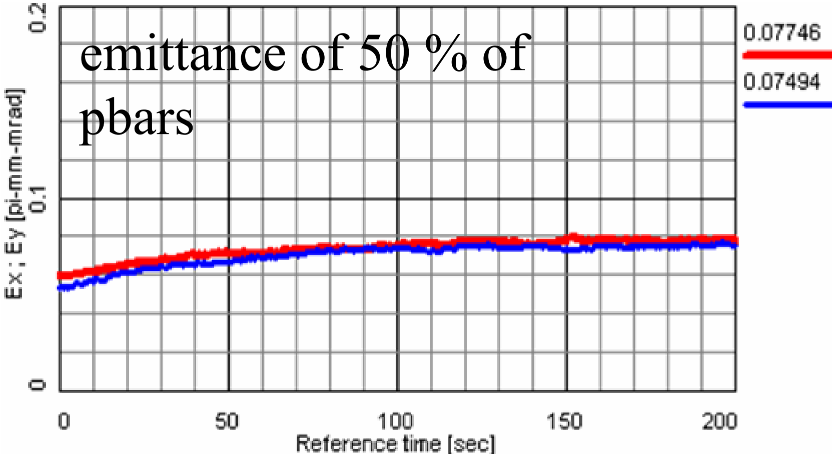

Calculated aspect of the beam on the target for $10^{10}$ 8 GeV electron-cooled antiprotons on target

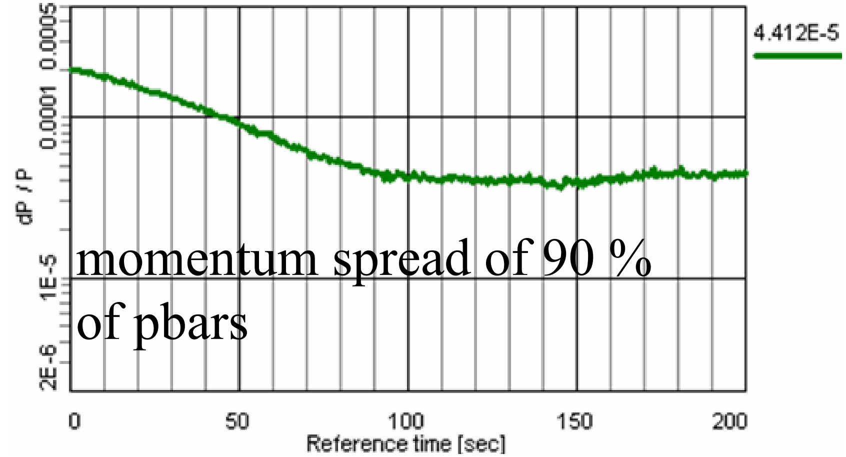


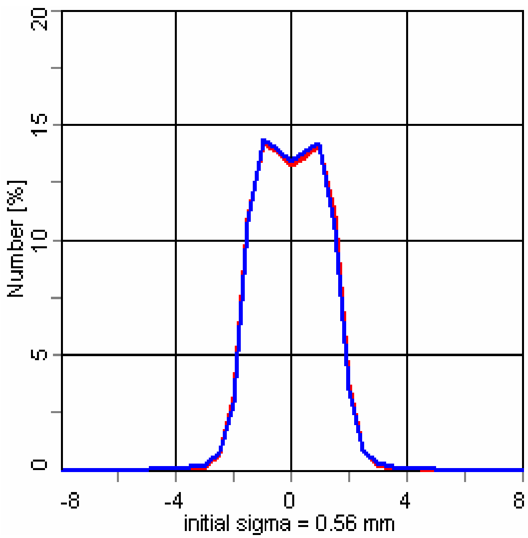

Calculated equilibrium transverse beam profiles of $10^{10}$ 8 GeV electron-cooled antiprotons on target in units of the initial rms. beam size of 0.56 mm

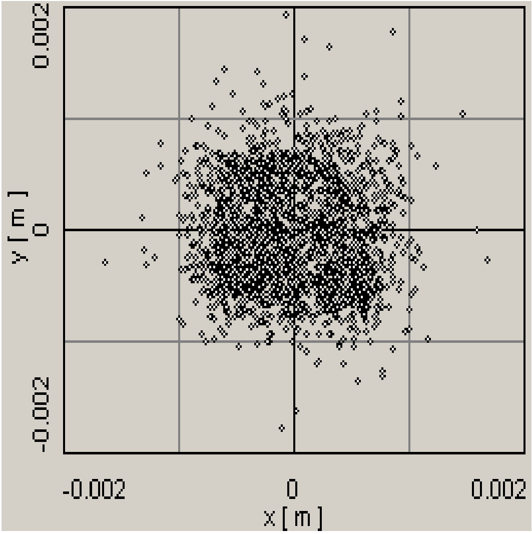
# RESULTS

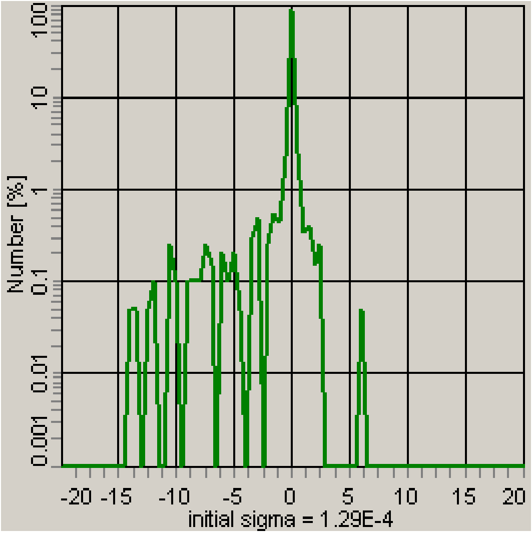
8.9 GeV/$c$, $10^{10}$ pbars



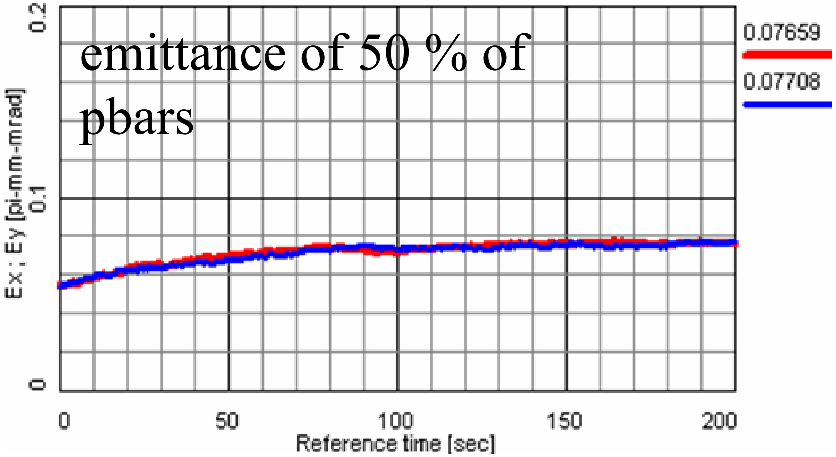



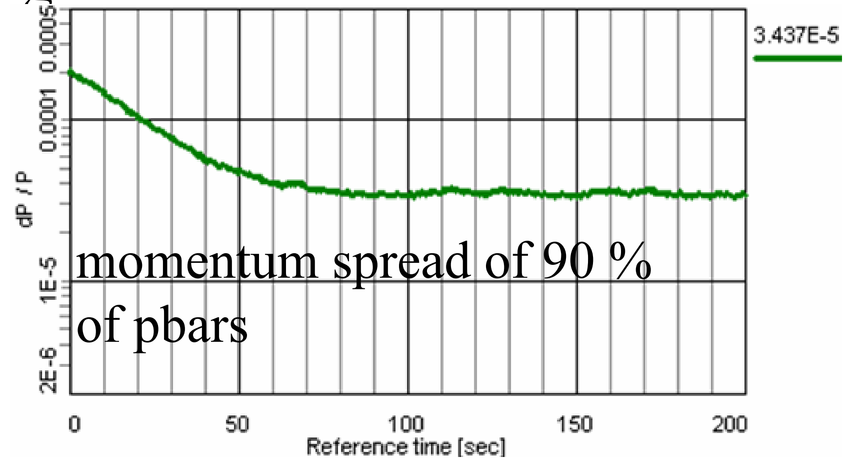



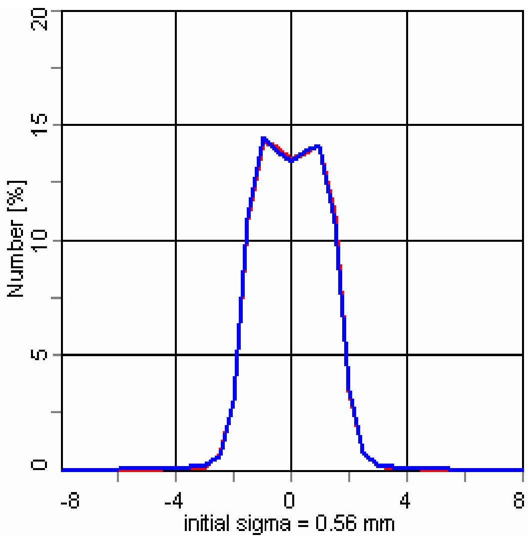

calculated lifetime 6,000 s

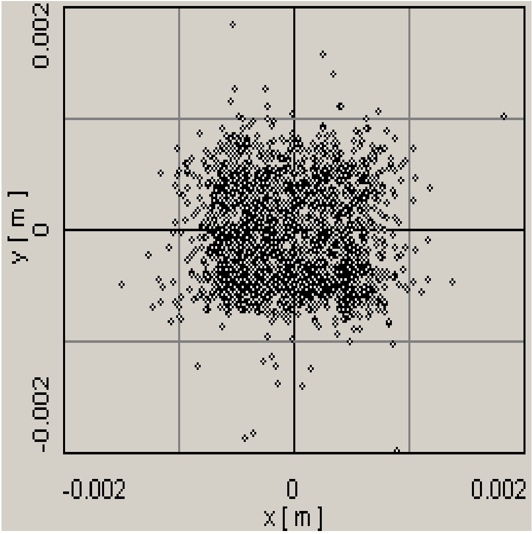
# RESULTS

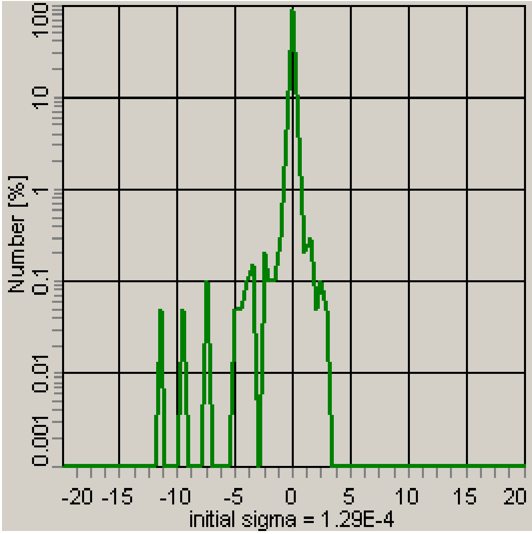
8.9 GeV/$c$, $10^{10}$ pbars, with stochastic as well as electron cooling



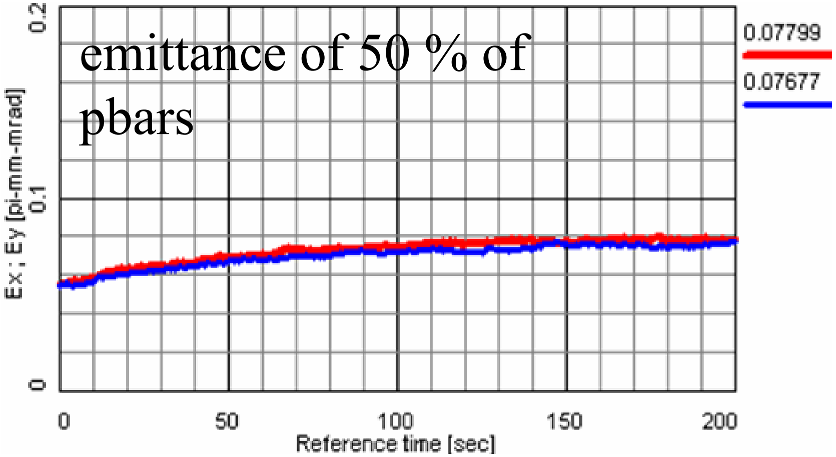



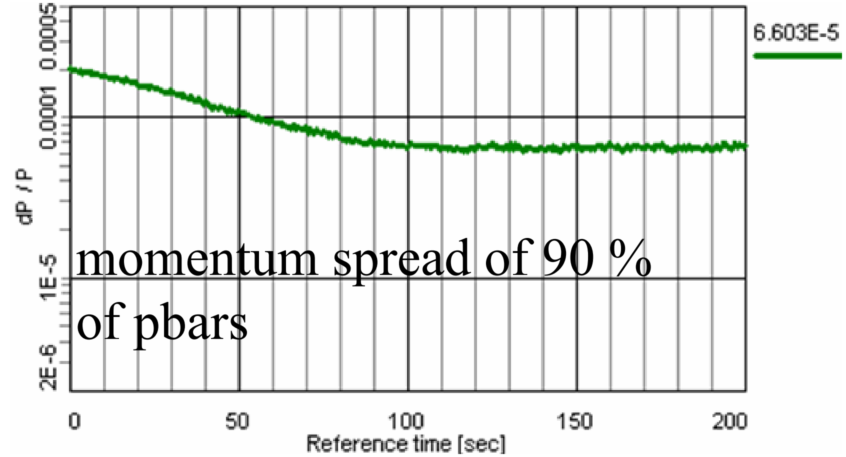



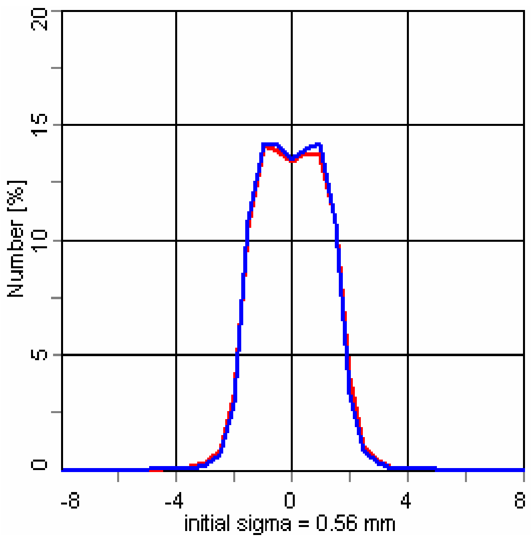

calculated lifetime 6,000 s

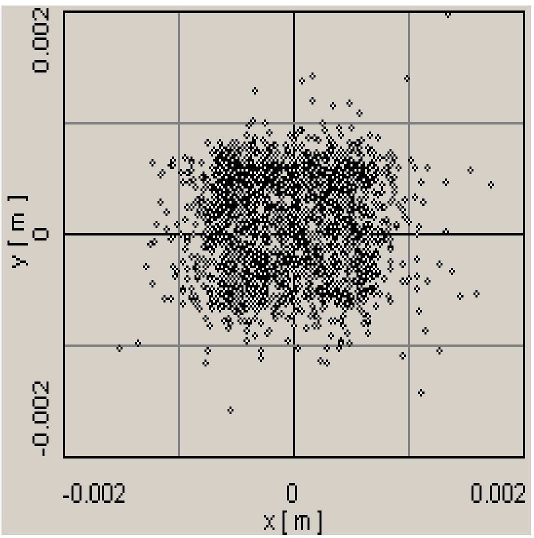
# RESULTS

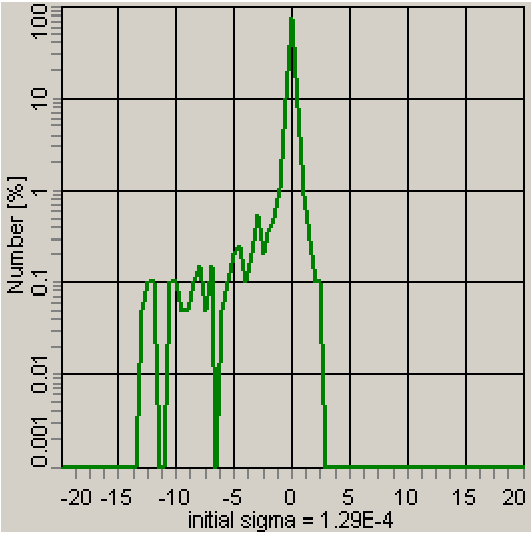
## 8.9 GeV/$c$, $10^{11}$ pbars (no stochastic cooling)



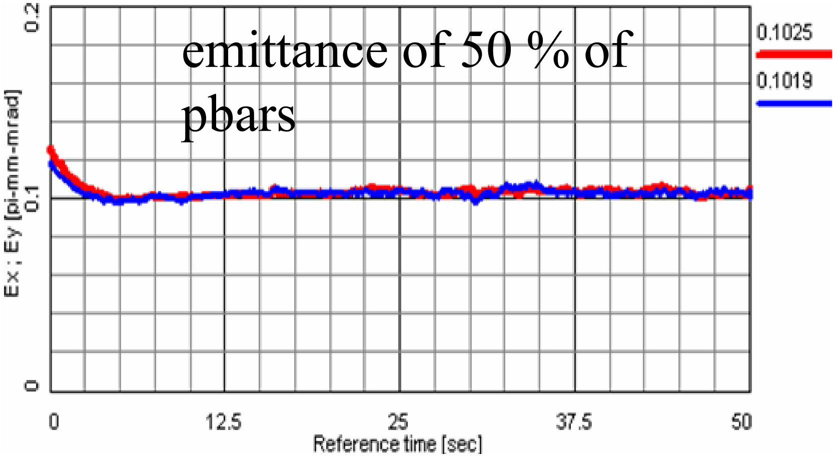



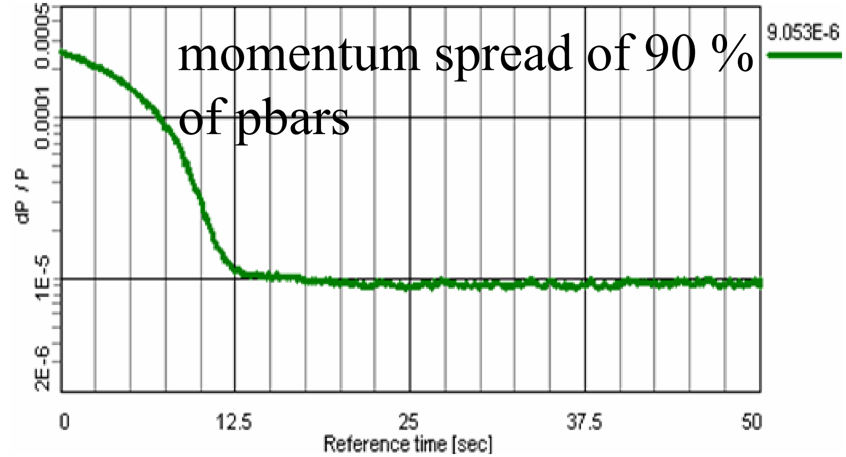



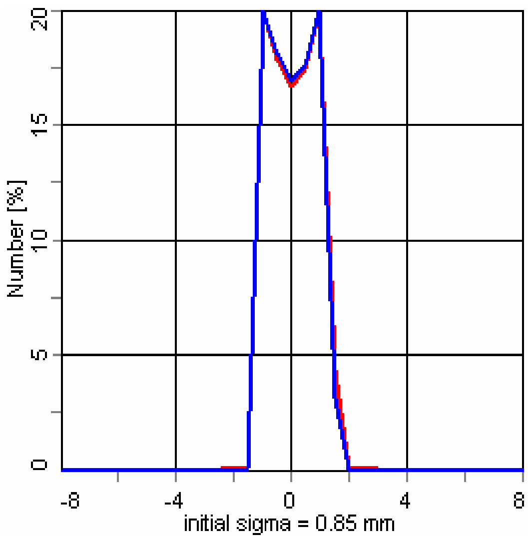



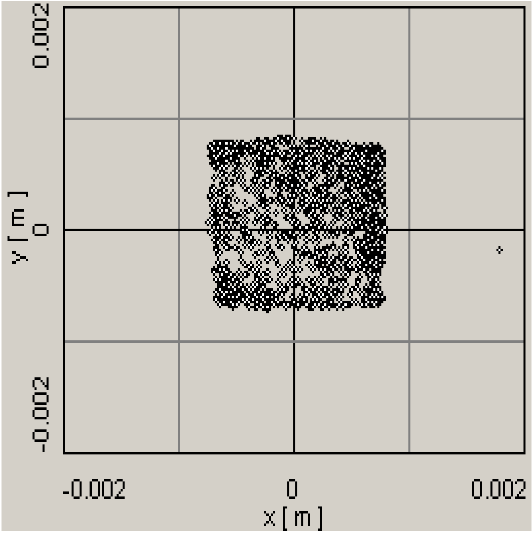
# RESULTS

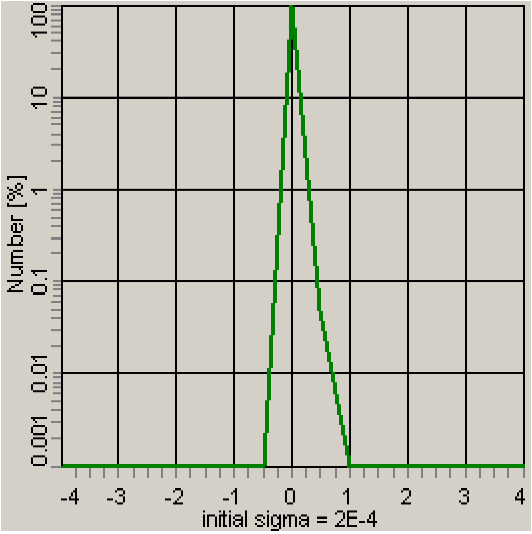
3.8 GeV/$c$, $10^{10}$ pbars



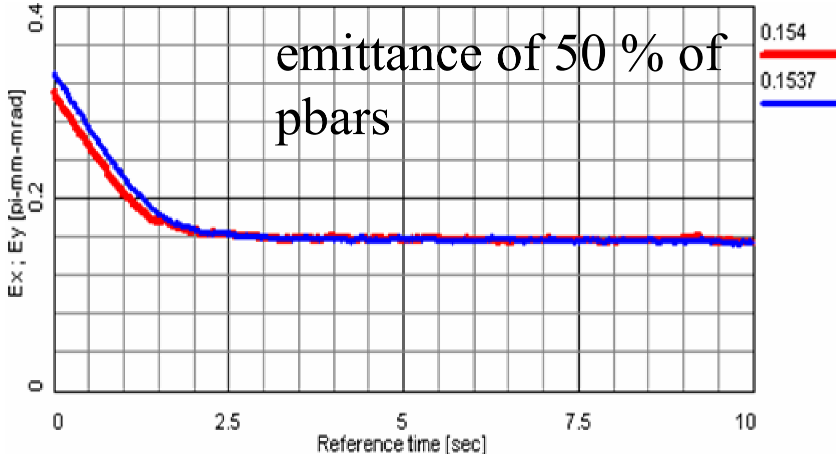



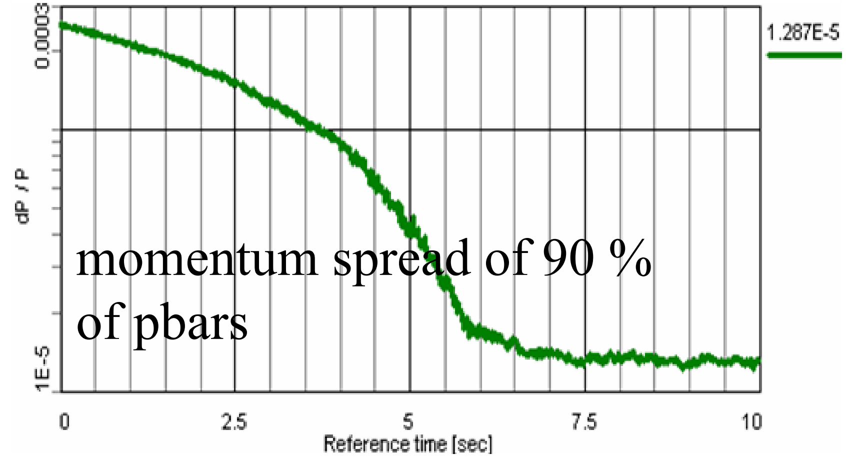



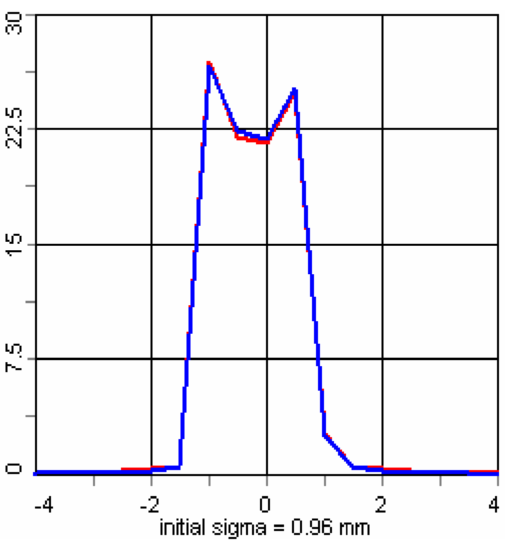

Beam lifetime 4,700 s

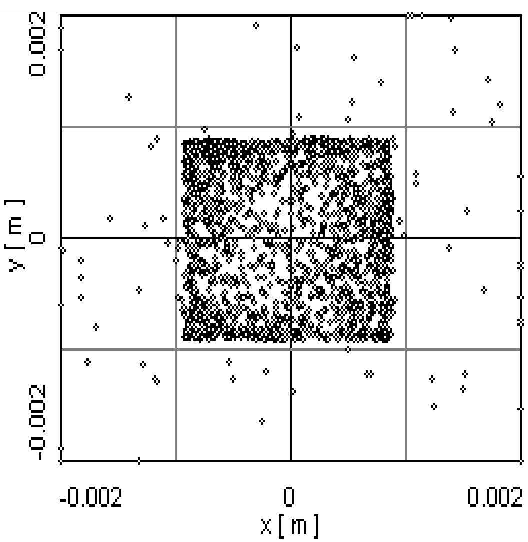
**RESULTS**

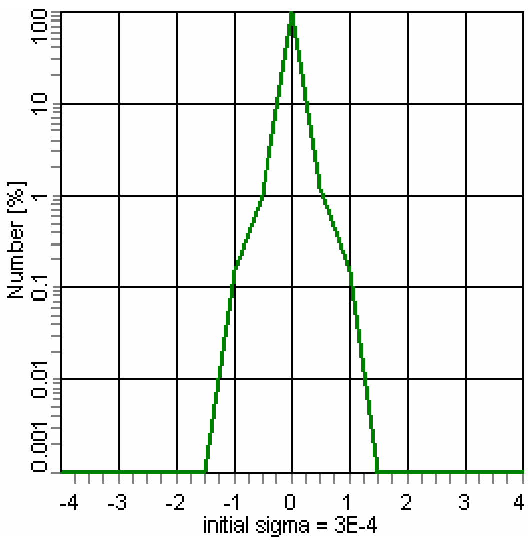
1.5 GeV/$c$, $10^{10}$ pbars



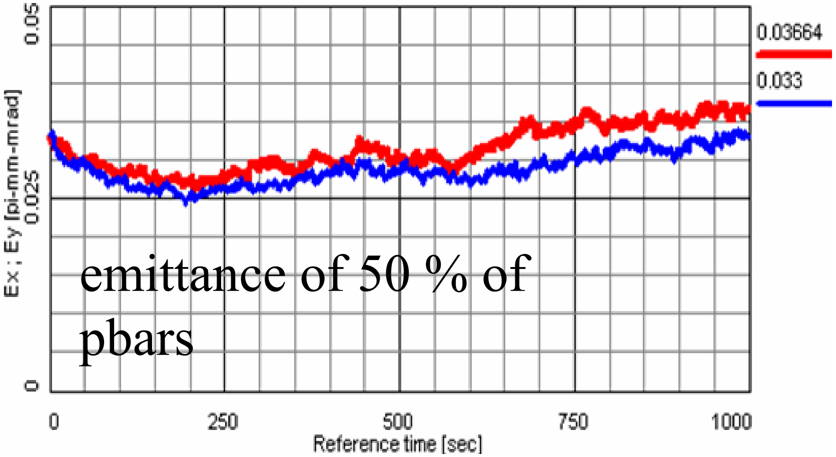



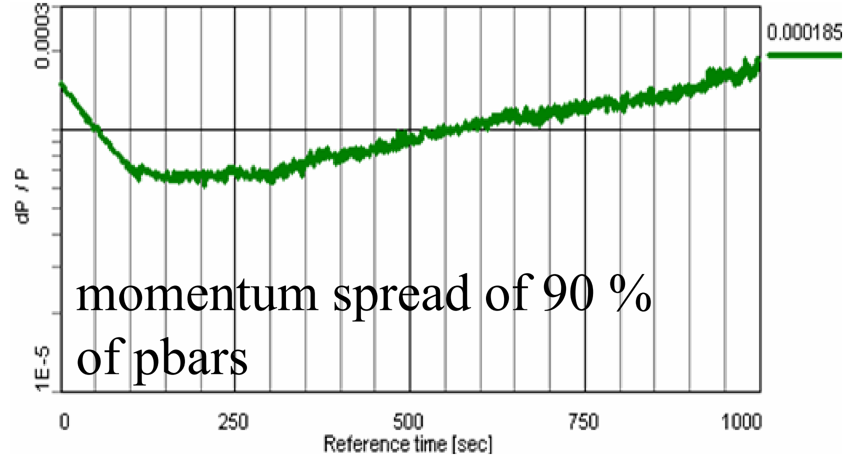



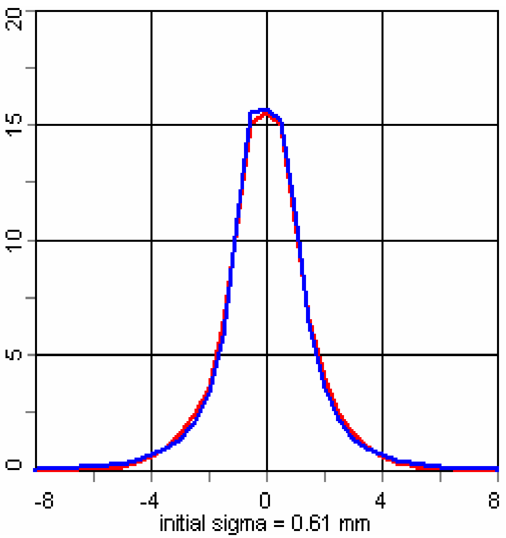

Beam lifetime 2,600 s

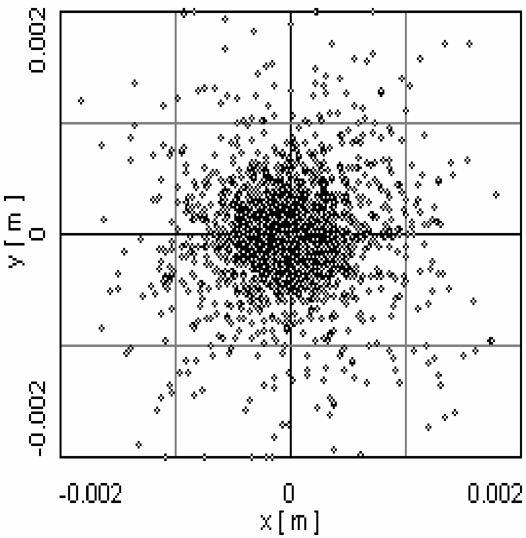
# RESULTS

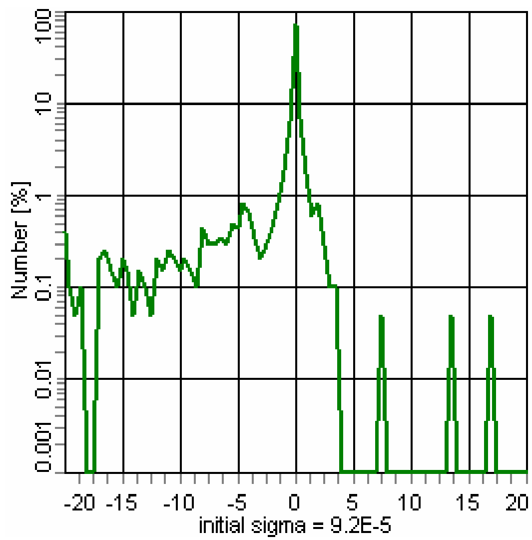
15 GeV/$c$, $10^{10}$ pbars



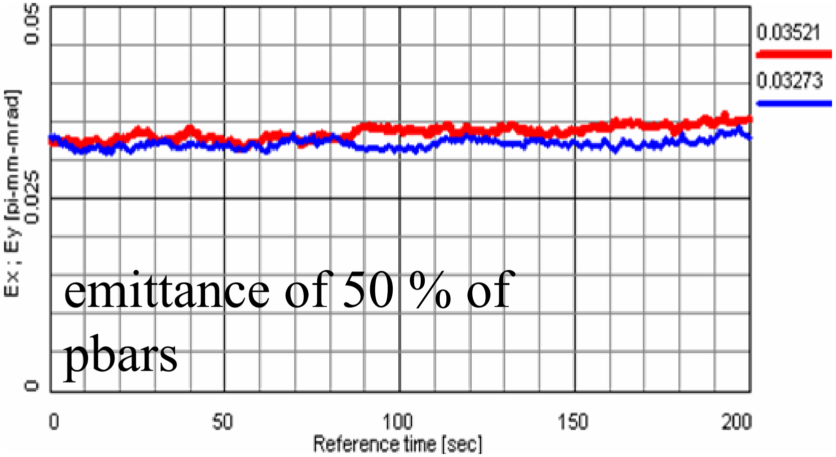



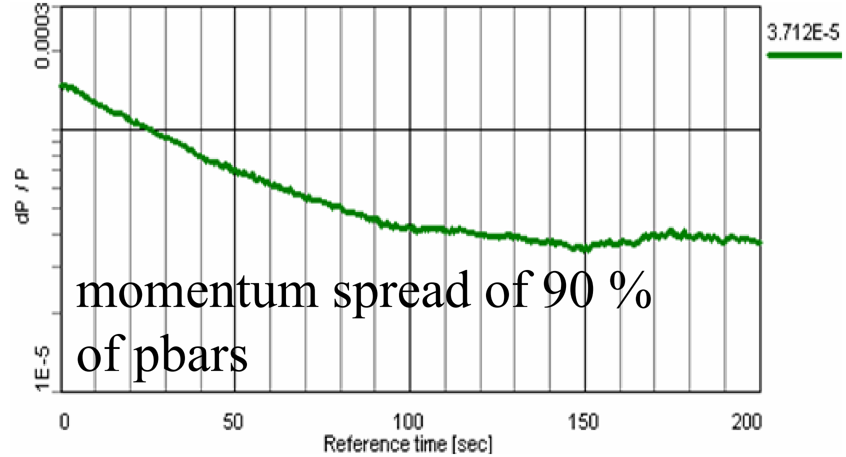

Beam lifetime 7,000 s

# RESULTS

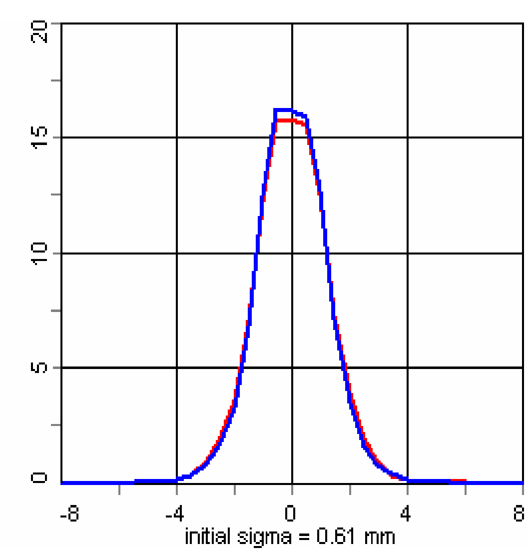
15 GeV/$c$, $10^{10}$ pbars, with stochastic as well as electron cooling

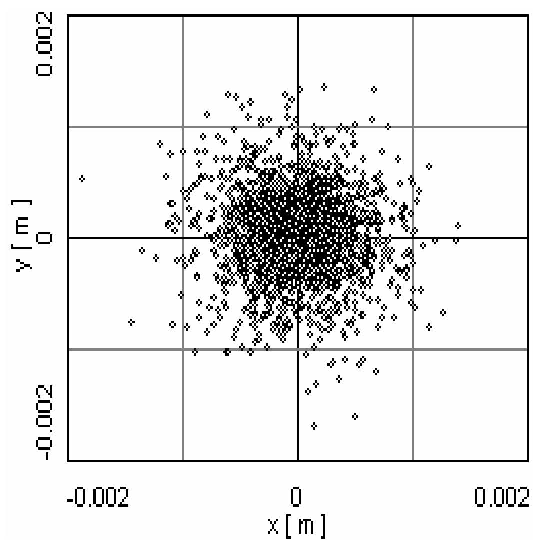


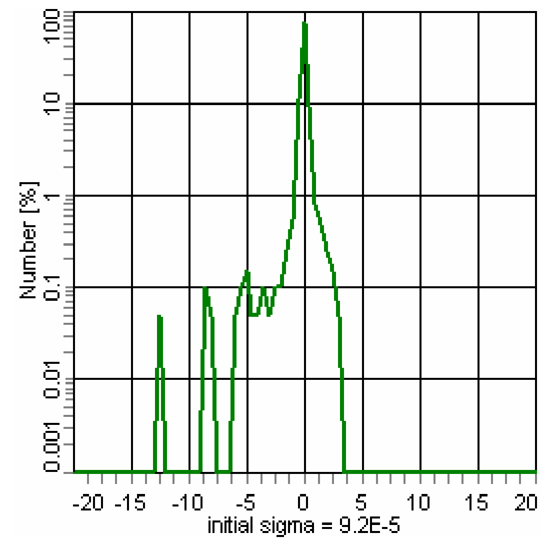

emittance of 50 % of pbars




momentum spread of 90 % of pbars




Beam lifetime 7,000 s

CONCLUSIONS

"Square" beam spot with side 1.6 mm achieved with appropriate choice of beta values at target and tilting the electron beam ("Hopf bifurcation").

90 % momentum spreads:

| | |
|---|---|
| 1.5 GeV/$c$ | $1.3\times10^{-5}$ |
| 3.8 GeV/$c$ | $9.0\times10^{-6}$ |
| 8.9 GeV/$c$ | $3.4\times10^{-5}$ |
| 15.0 GeV/$c$ | $3.7\times10^{-5}$ |

with stochastic as well as electron cooling