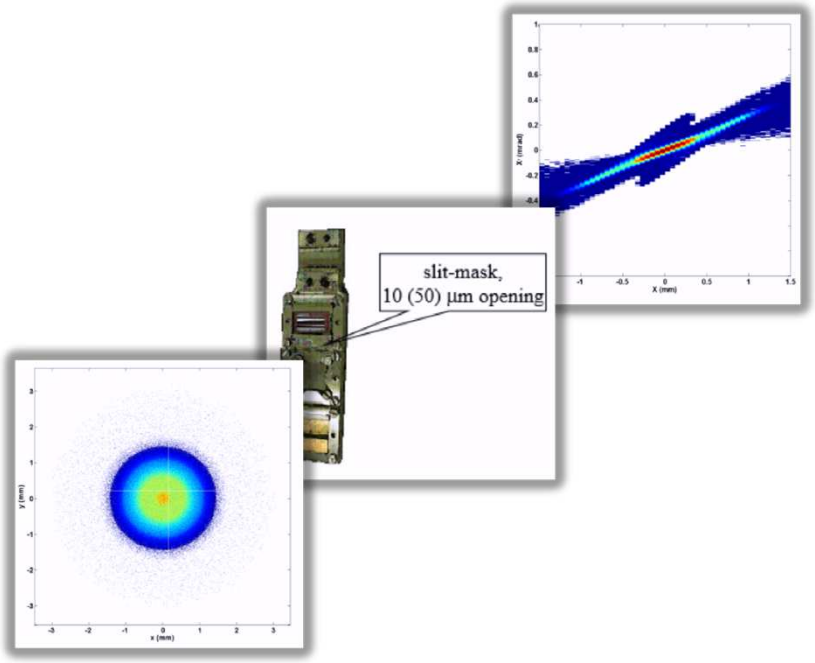
Study of Space Charge Effect in Emittance Measurement by Slit-scan Technique



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PITZ Physics Seminar

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HELMHOLTZ ASSOCIATION

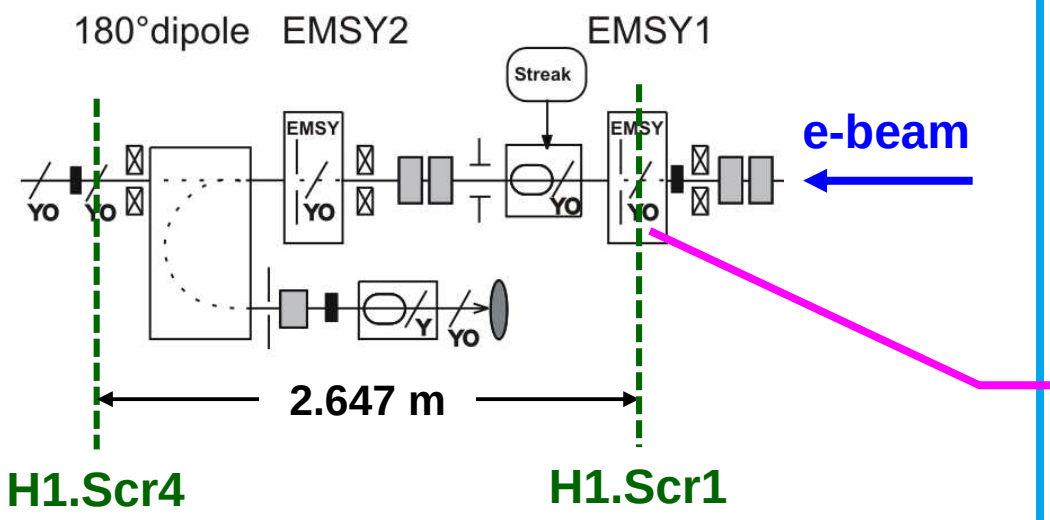
PITZ Photo Injector Test Facility Zeuthen

DESY

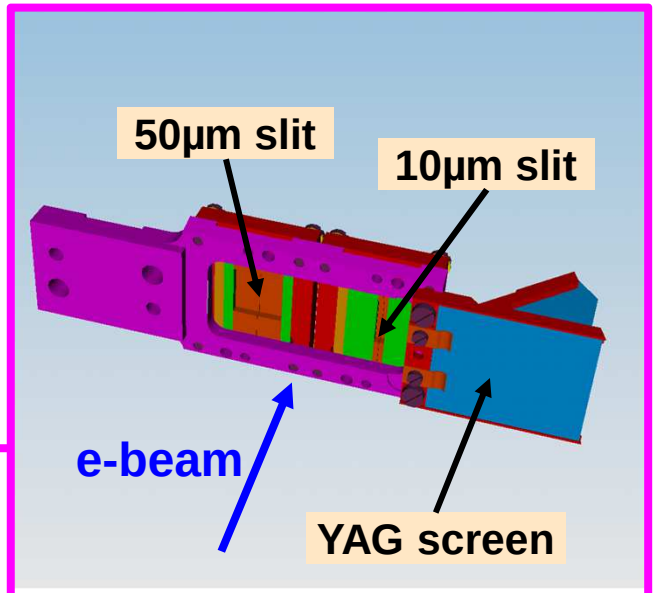
Outline

- **Introduction**
- **Reviews of Transverse Emittance Measurement by Single Slit-scan Technique (SST)**
- **Simulation of SST**
- **Results**
- **Summary & Outlook**

Introduction



Layout of EMSY1 section in PITZ beam-line



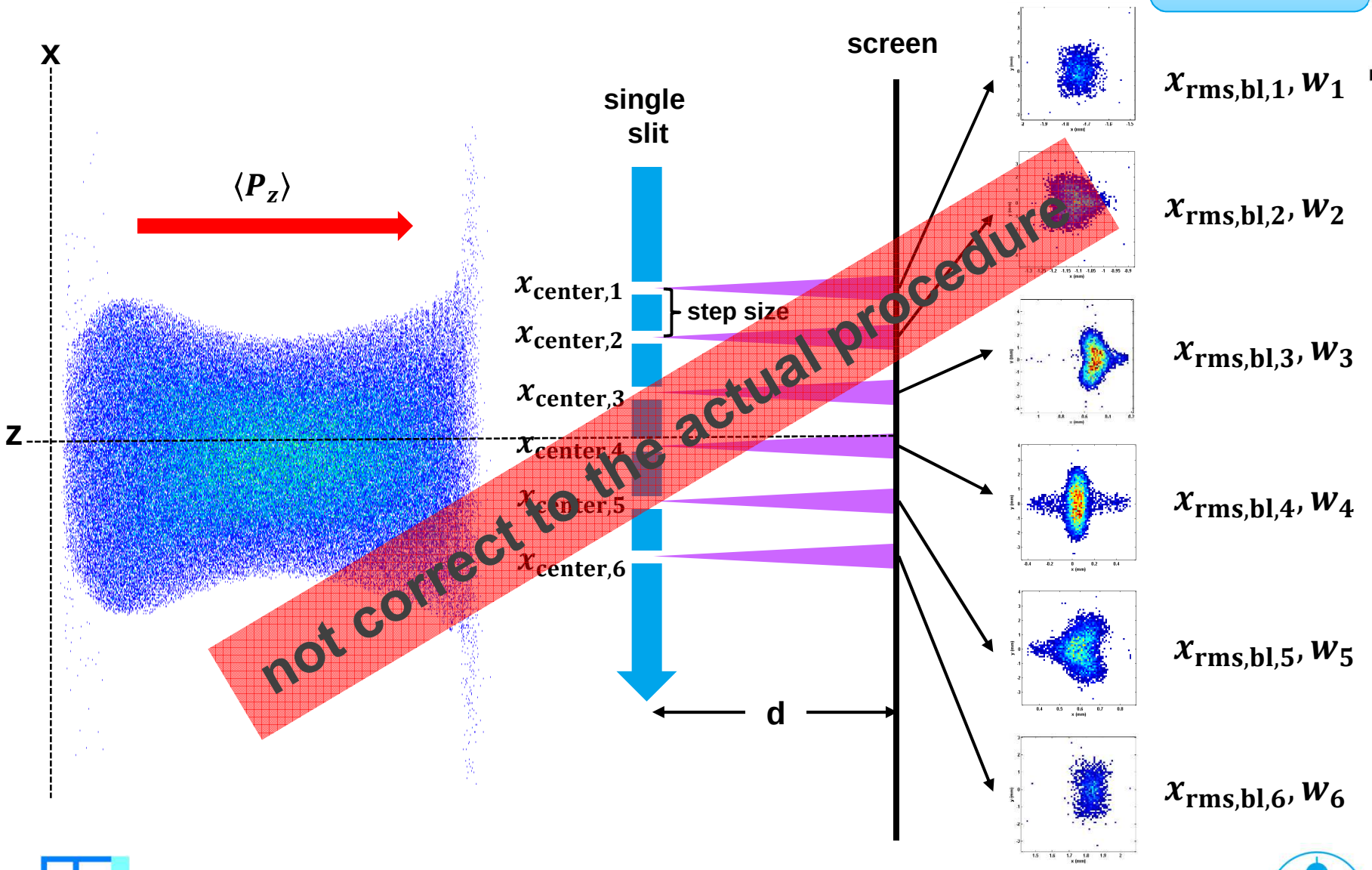
Model of actuator in EMSY1

Objectives of This Work

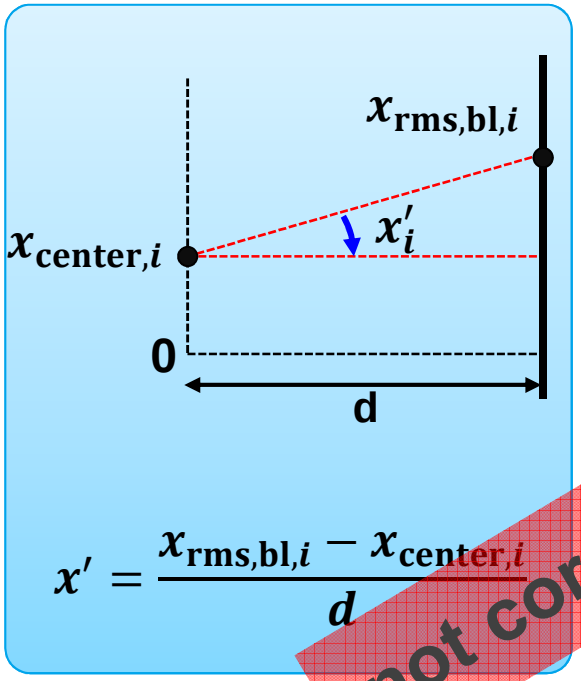
- Reviews the methodical approach of SST
- Study of space charge effect in SST

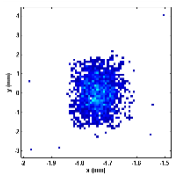
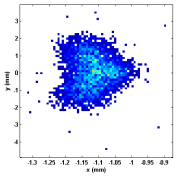
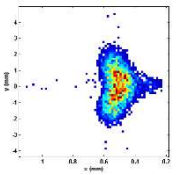
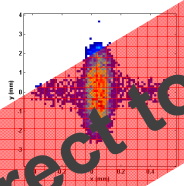
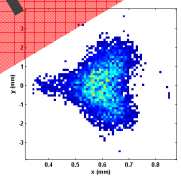
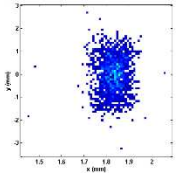
Reviews of SST

$$w_i = \frac{N_{\text{data,i}}}{\sum N_{\text{data,i}}}$$



Reviews of SST (2)



$x_{\mathrm{rms,bl},1} \rightarrow x'_1 \rightarrow (x_{\mathrm{center},1}, x'_1)$

$x_{\mathrm{rms,bl},2} \rightarrow x'_2 \rightarrow (x_{\mathrm{center},2}, x'_2)$

$x_{\mathrm{rms,bl},3} \rightarrow x'_3 \rightarrow (x_{\mathrm{center},3}, x'_3)$

$x_{\mathrm{rms,bl},4} \rightarrow x'_4 \rightarrow (x_{\mathrm{center},4}, x'_4)$

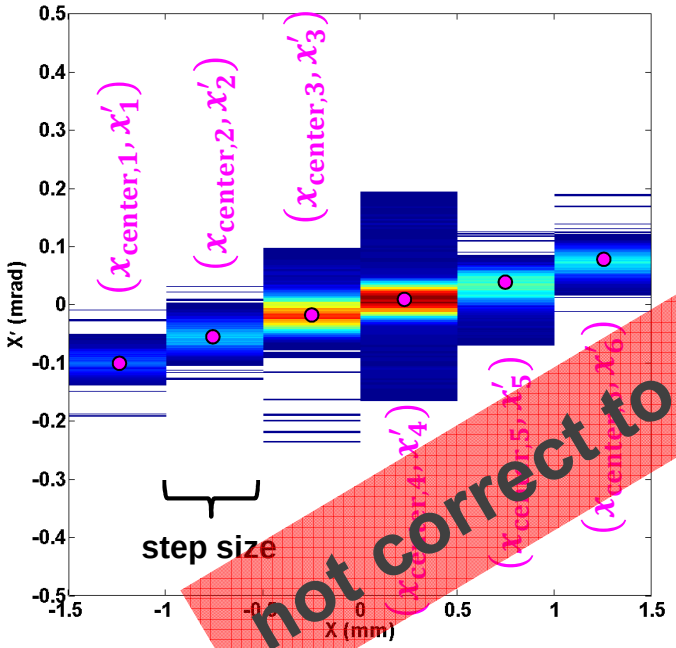
$x_{\mathrm{rms,bl},5} \rightarrow x'_5 \rightarrow (x_{\mathrm{center},5}, x'_5)$

$x_{\mathrm{rms,bl},6} \rightarrow x'_6 \rightarrow (x_{\mathrm{center},6}, x'_6)$

not correct to the actual procedure

Reviews of SST (3)

Trace Space Reconstruction



Equations for Emittance Calculation

$$\langle x^2 \rangle = \sum w_i x_{center,i}^2$$

$$\langle x'^2 \rangle = \sum w_i x'^2_i$$

$$\langle x x' \rangle = \sum w_i x_{center,i} x'_i$$

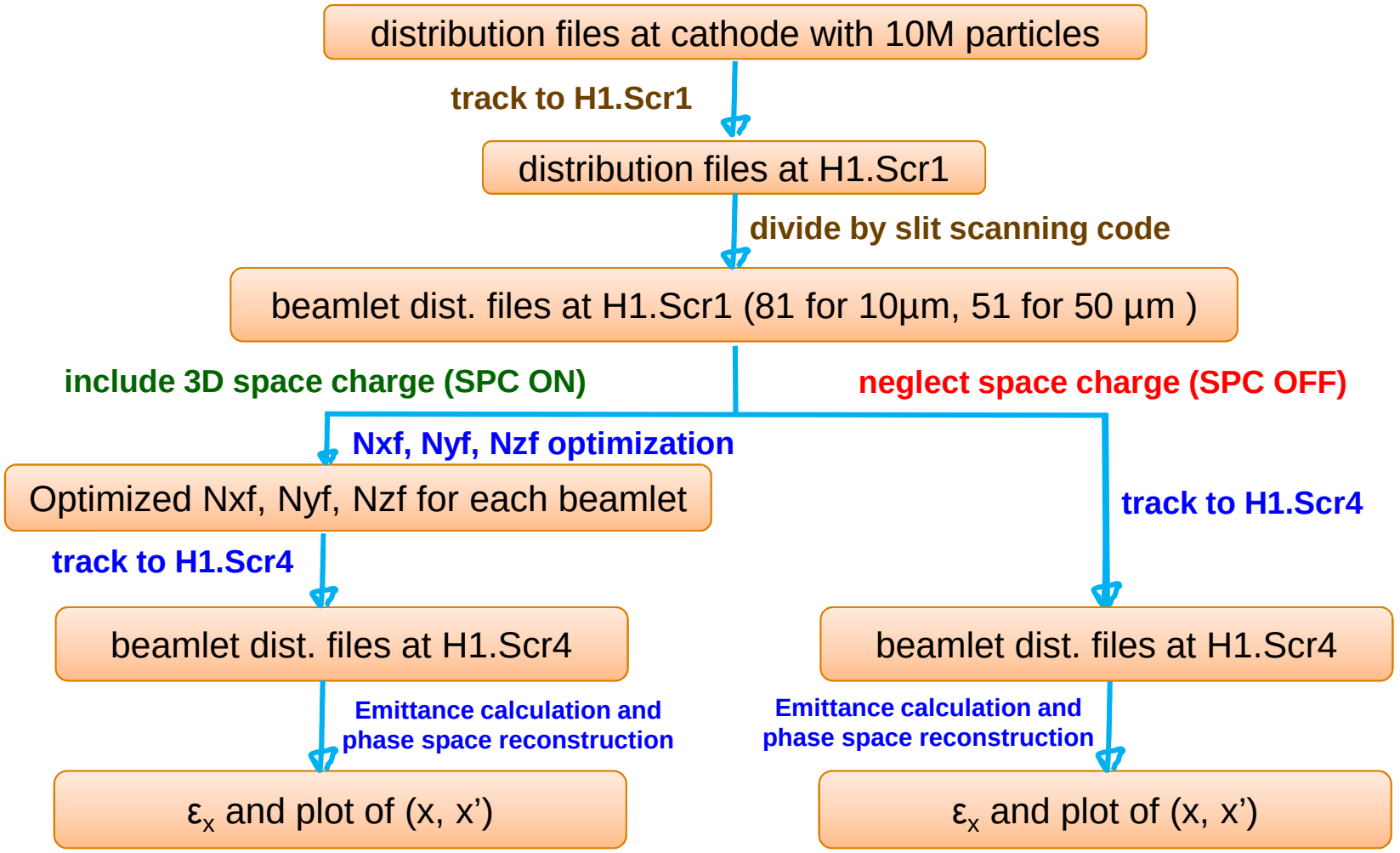
$$\varepsilon_{x,n} = \frac{\langle P_z \rangle}{m_e c} \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2}$$

$$\text{scale factor} = \frac{\sigma_{x,\text{real beam}}}{\sqrt{\langle x^2 \rangle}} = \frac{\sigma_{x,\text{real beam}}}{\sigma_{x,\text{scan}}}$$

$$\varepsilon_{x,n,scaled} = (\text{scale factor}) \varepsilon_{x,n}$$

not correct to the actual procedure

Simulation of SST: Working Process



Finally, We will have 4 plots of reconstructed trace spaces:

10µm SPC OFF, 10µm SPC ON, 50µm SPC OFF and 50µm SPC ON

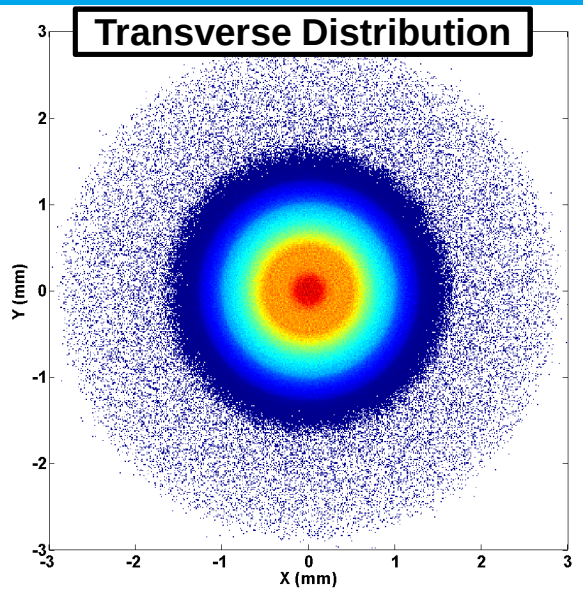
Simulation of SST: Electron Beam Profiles at H1.Scr1

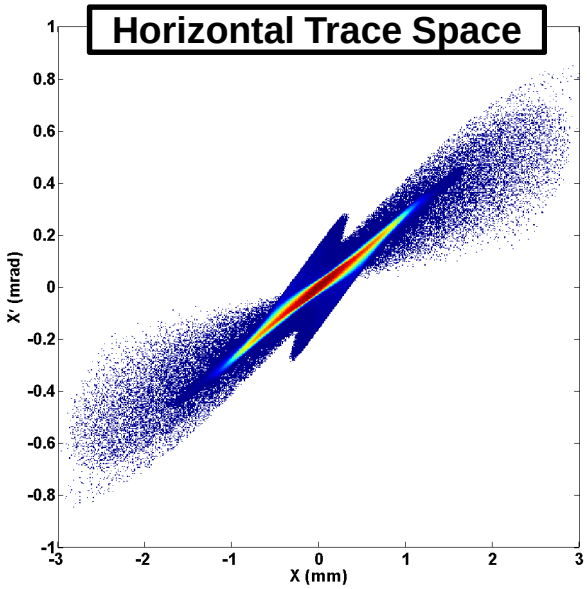
Input Parameters for ASTRA

$N_{particles}$	10M	
bunch charge	1	nC
laser spot size	0.4	mm
$I_{main\ solenoid}$	386	A
$E_{gun,max}$	60.5	MV/m
Φ_{gun}	-1.0	deg
$E_{booster,max}$	17.5	MV/m

Beam Parameters at H1.Scr1

$\sigma_{x,rms}$	0.575	mm
$\sigma_{y,rms}$	0.575	mm
$\varepsilon_{x,n}$	0.617	mm.mrad
$\varepsilon_{y,n}$	0.617	mm.mrad
$P_{z,avg}$	21.625	MeV/c



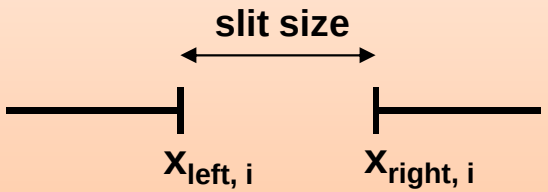


Simulation of SST: Building Beamlet Distribution Files

Divide beam into beamlets by slit scanning code

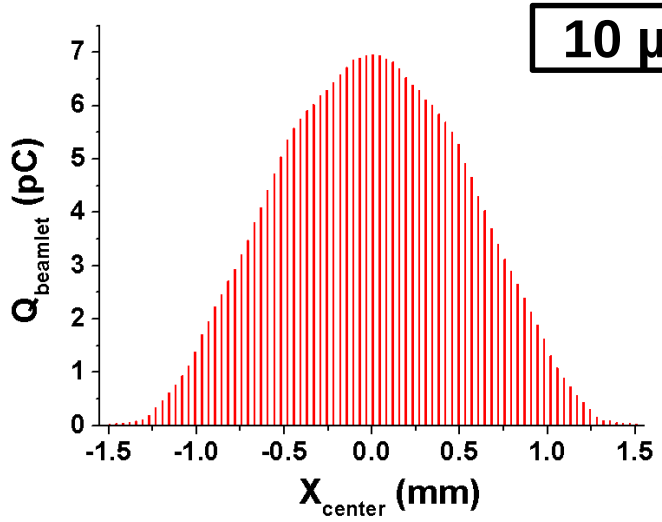
Scan range	-1.50 to 1.50 mm	
Slit size	10 µm	50 µm
N_{step}	81	51
Step size	37.5 µm	60 µm

Slit parameters



$x_{center,\ i} = x_{left,\ i} + (0.5*\text{slit size})$

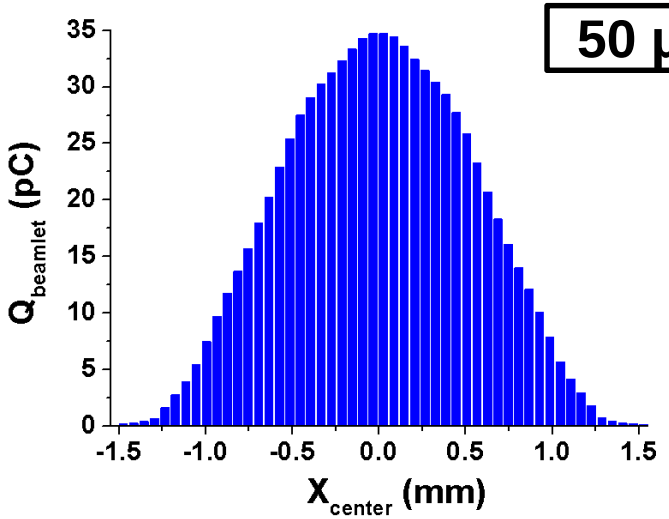
10 µm, 81 steps



$Q_{total} = 0.266\ \text{nC}$

$\frac{\Delta Q}{1\ \text{nC}} = -73.4\ \%$

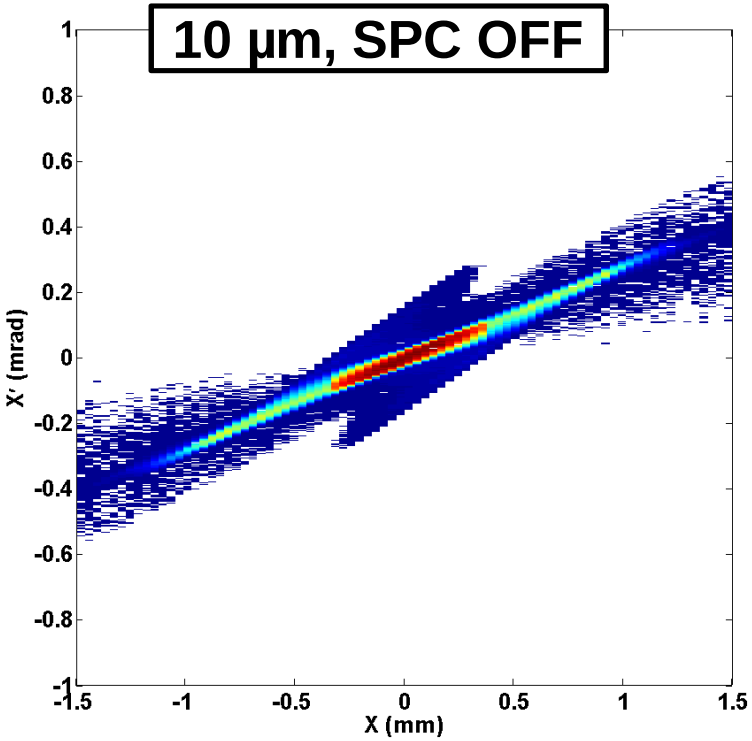
50 µm, 51 steps

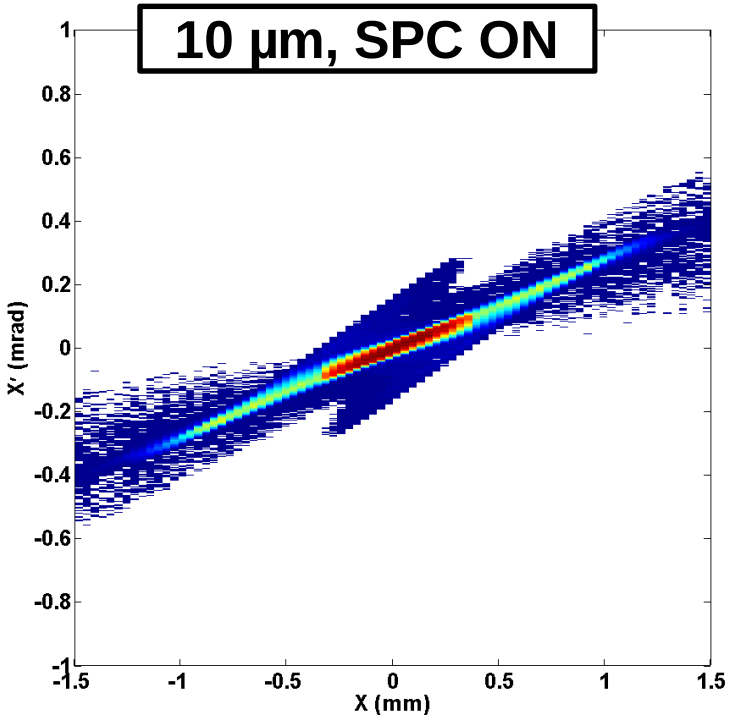


$Q_{total} = 0.831\ \text{nC}$

$\frac{\Delta Q}{1\ \text{nC}} = -16.9\ \%$

Results: Slit Size of 10 µm



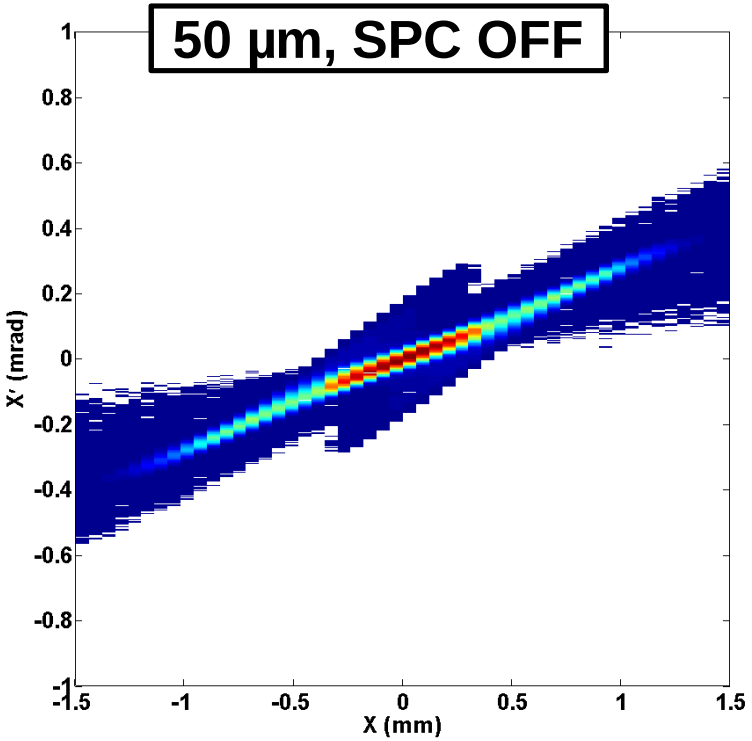


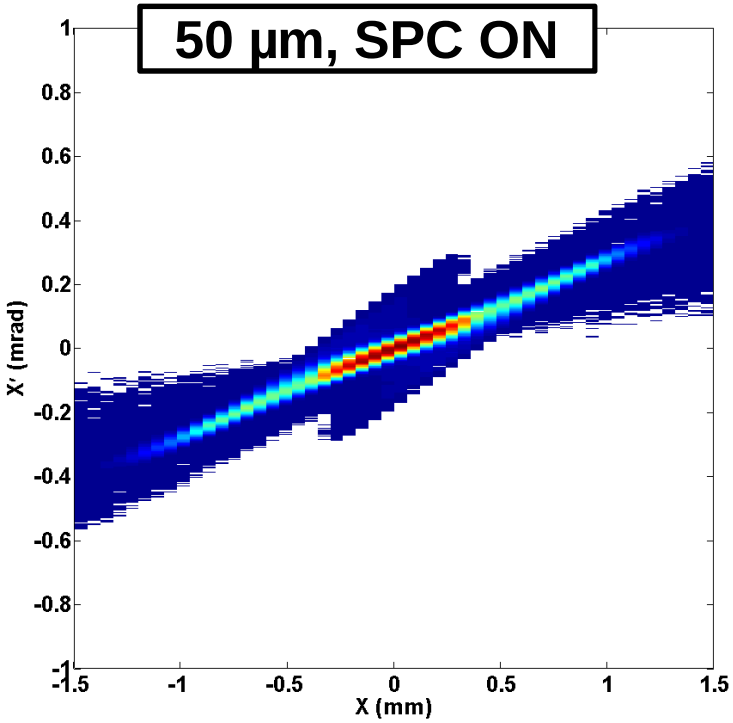
$\sigma_{x,scan}$	0.5207 mm
scale factor	1.0109
$\varepsilon_{x,n,no\ scaled}$	0.6001 mm.mrad
$\varepsilon_{x,n,scaled}$	0.6066 mm.mrad

$\sigma_{x,scan}$	0.5207 mm
scale factor	1.0109
$\varepsilon_{x,n,no\ scaled}$	0.6051 mm.mrad
$\varepsilon_{x,n,scaled}$	0.6117 mm.mrad

$\varepsilon_{x,n,reference}$ = 0.617 mm.mrad

Results: Slit Size of 50 µm





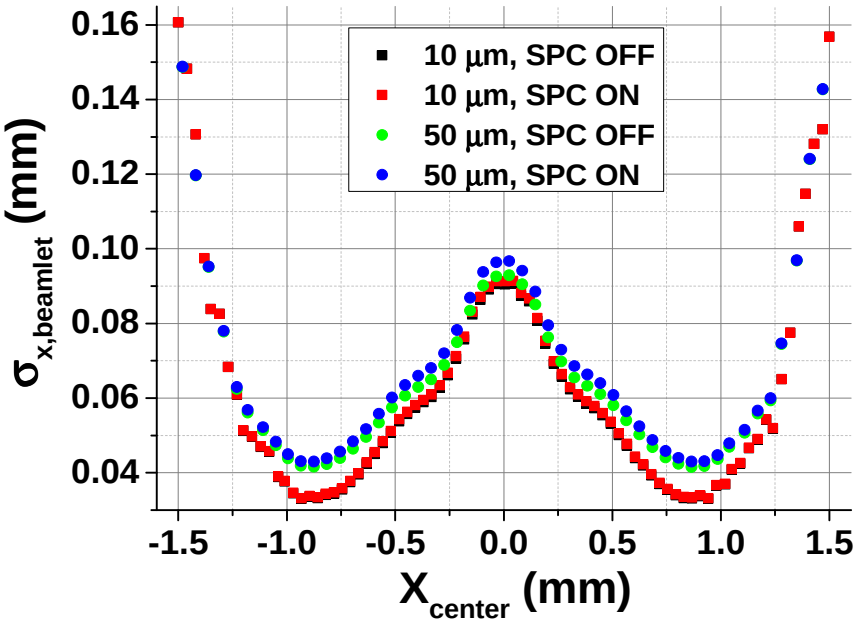
$\sigma_{x,scan}$	0.5209 mm
scale factor	1.0104
$\varepsilon_{x,n,no\ scaled}$	0.6376 mm.mrad
$\varepsilon_{x,n,scaled}$	0.6443 mm.mrad

$\sigma_{x,scan}$	0.5209 mm
scale factor	1.0104
$\varepsilon_{x,n,no\ scaled}$	0.6619 mm.mrad
$\varepsilon_{x,n,scaled}$	0.6688 mm.mrad

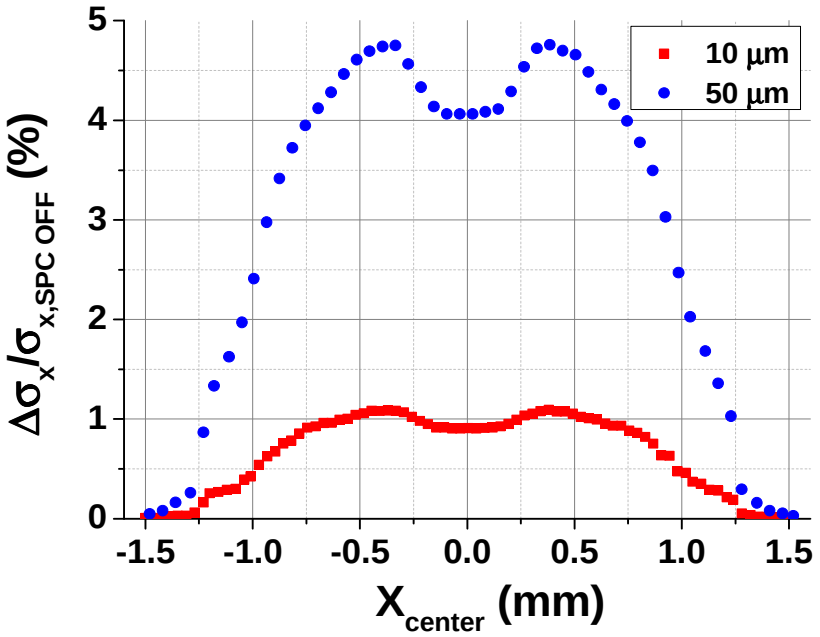
$\varepsilon_{x,n,reference}$ = 0.617 mm.mrad

Results: Beamlet Size at H1.Scr4

Rms Size of Beamlet at H1.Scr4



Error of Beamlet Size at H1.Scr4



Results: Summary Table

Parameter	Beam Dist. File	10 µm SPC OFF	10 µm SPC ON	50 µm SPC OFF	50 µm SPC ON
Q (nC)	1	0.266	0.266	0.831	0.831
$\Delta Q / Q_{ref}$		-73.4%	-73.4%	-16.9%	-16.9%
$\sigma_{x,real\ beam}$ (mm)	0.5750				
$\sigma_{x,scan}$ (mm)		0.5207	0.5207	0.5209	0.5209
scale factor		1.0109	1.0109	1.0104	1.0104
$\varepsilon_{x,n,scaled}$ (mm.mrad)	**0.617**	0.6066	0.6117	0.6443	0.6688
$\Delta\varepsilon / \varepsilon_{x,n,ref}$		-1.69%	-0.86%	+4.42%	+8.40%
$\Delta\varepsilon / \varepsilon_{x,n,SPC\ OFF}$			**+0.84%**		**+3.80%**
$\sigma_{x,bl,mid}$ (mm)		0.0905	0.0913	0.0930	0.0967
$\Delta\sigma / \sigma_{x,bl,mid,SPC\ OFF}$			**+0.88%**		**+3.98%**

Summary & Outlook

Summary

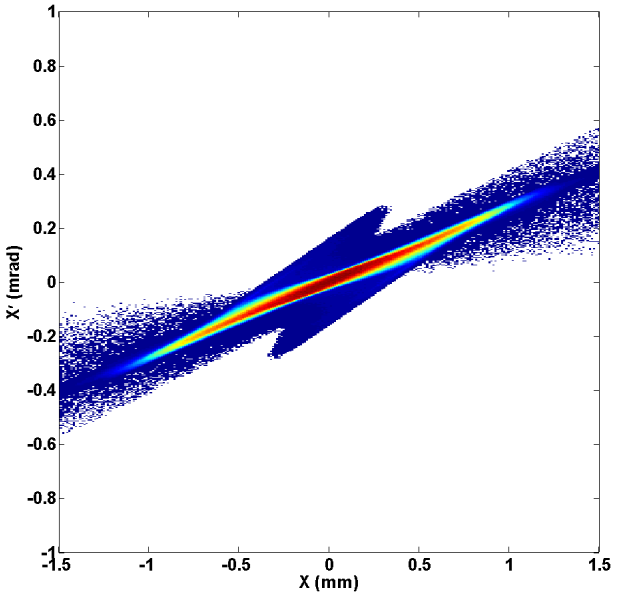
- Reviews of SST was done
- Space charge effect still plays significant role in SST for slit size of 50µm.
- We lost most of bunch charge when using slit size of 10µm. However, We could scan more precisely and got more accurate emittance.
- When comparison the results from SPC ON to SPC OFF
  - For slit size of 10µm, $\varepsilon_{x,n}$ and $\sigma_{x,bl,mid}$ increase ~1%
  - For slit size of 50µm, $\varepsilon_{x,n}$ and $\sigma_{x,bl,mid}$ increase ~4%

Outlook

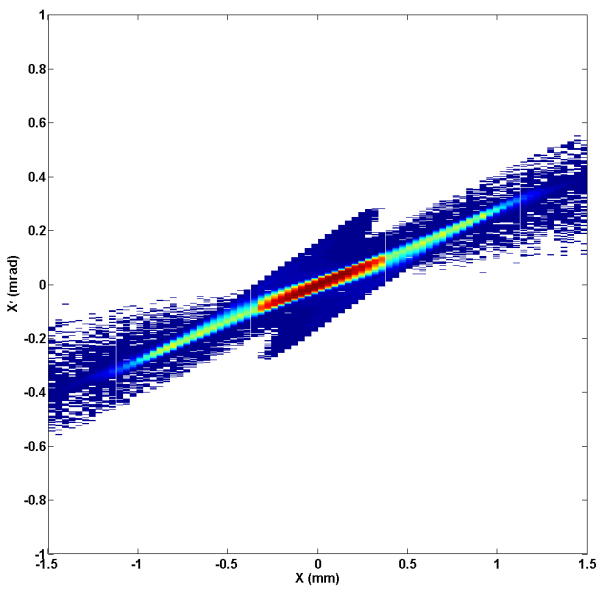
- Include the slit thickness into ASTRA simulation.
- Perform study with bunch charge of 2nC, 250pC, 100pC, and 20pC.

Backup: Comparison of Trace Spaces

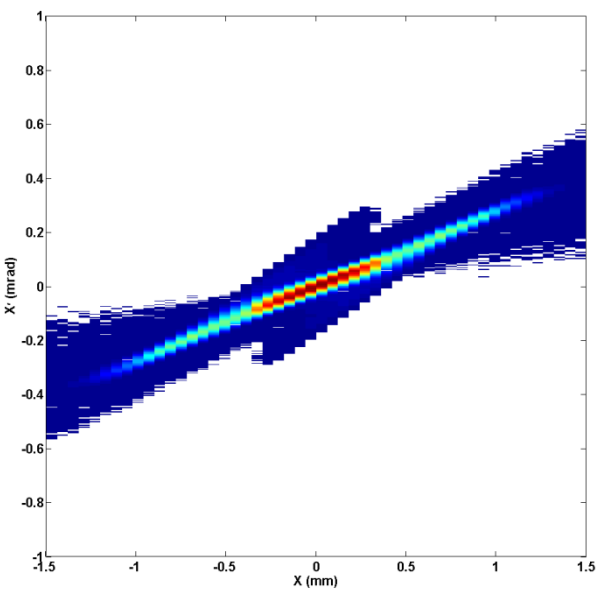
ASTRA



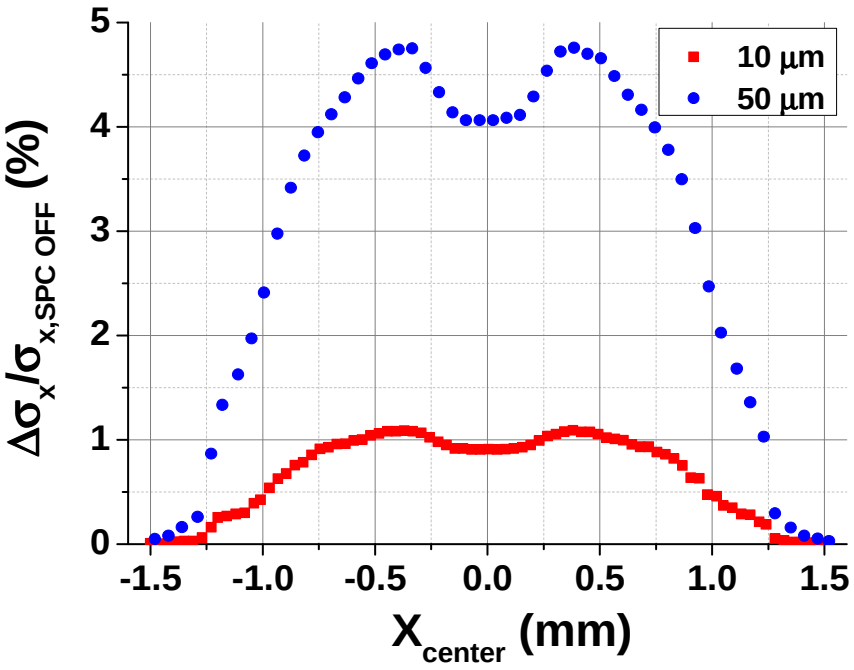
10 µm, SPC ON

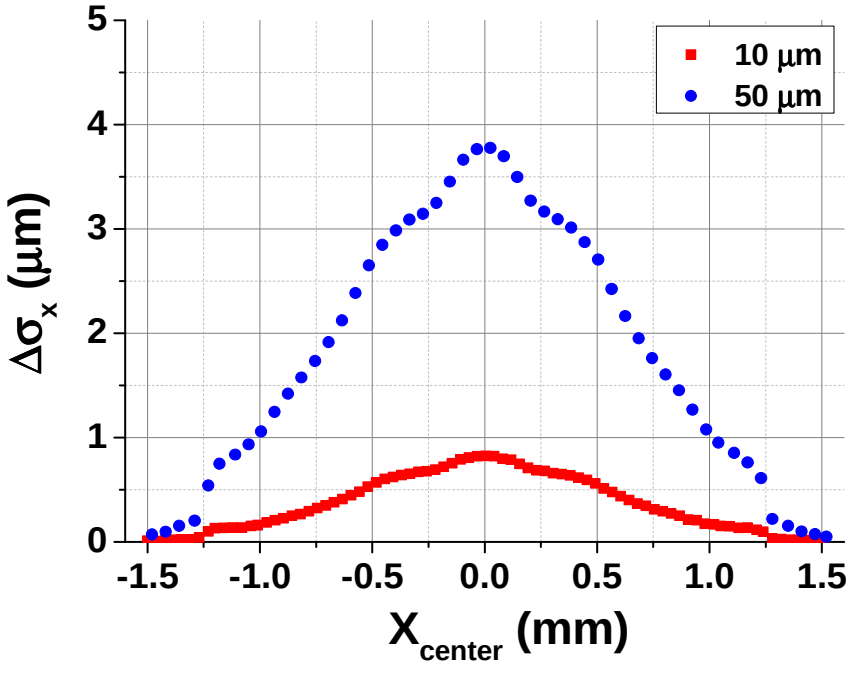


50 µm, SPC ON



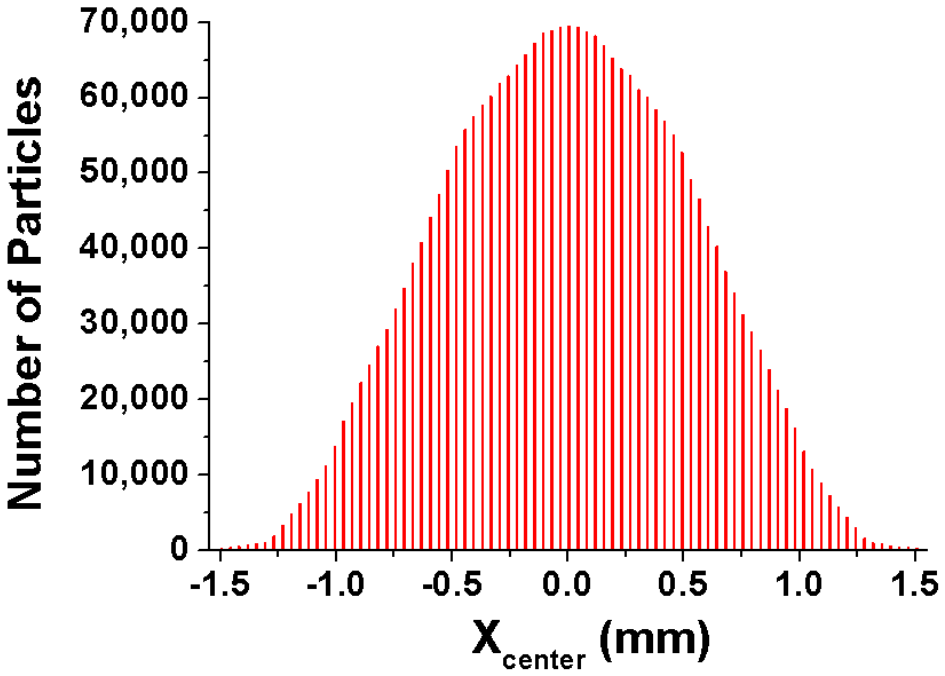
Backup: Error of Beamlet Size at H1.Scr4





Backup: Histogram for each case

10 µm, 81 steps



50 µm, 51 steps