Virtual Pepper Pot

- **Algorithm review**
- **Simulation**
- **Experiment: Methodic studies**

Namra Aftab
PITZ Physics Seminar
25-02-2021

VPP Algorithm

Review

- crossing of horizontal and vertical slits
- similar to pepper pot but multi-shot
- ability to perform 4D TPS measurements

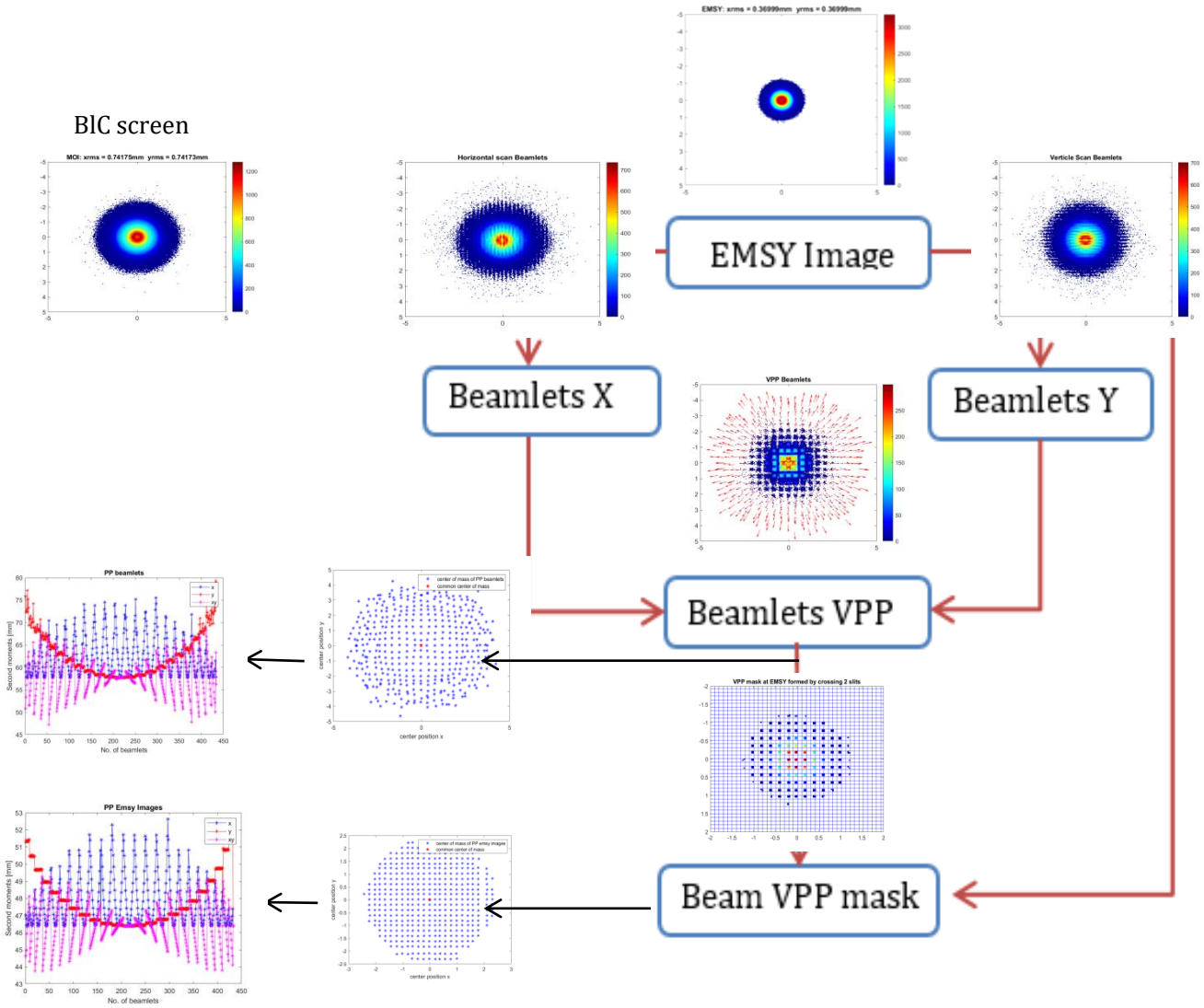
$$\sigma^{4D} = \begin{pmatrix} < x^2 > & < xx' > & < xy > & < xy' > \\ < xx' > & < x'^2 > & < x'y > & < x'y' > \\ < xy > & < x'y > & < y^2 > & < yy' > \\ < xy' > & < x'y' > & < yy' > & < y'^2 > \end{pmatrix} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{xy}^T & \sigma_{yy} \end{pmatrix}$$

$$\epsilon_x = \sqrt{< xx >< x'x > - < xx' >^2}$$

$$\epsilon_y = \sqrt{< yy >< y'y > - < yy' >^2}$$

$$C_{xy} = \sqrt{\langle xy \rangle \langle x'y' \rangle - < xy' >< x'y >}$$

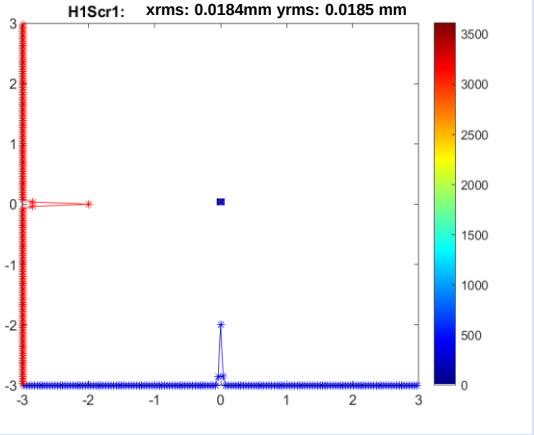
$$\epsilon_{4D}^2 = \det(\sigma^{4D}) = \epsilon_x^2 \epsilon_y^2 - C_{xy}^4$$

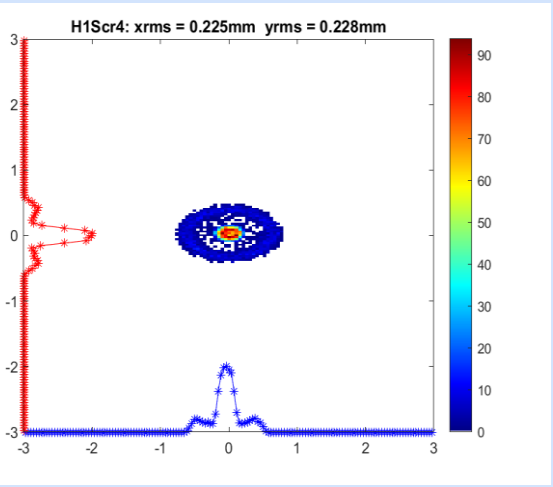


VPP Algorithm-crossing slits

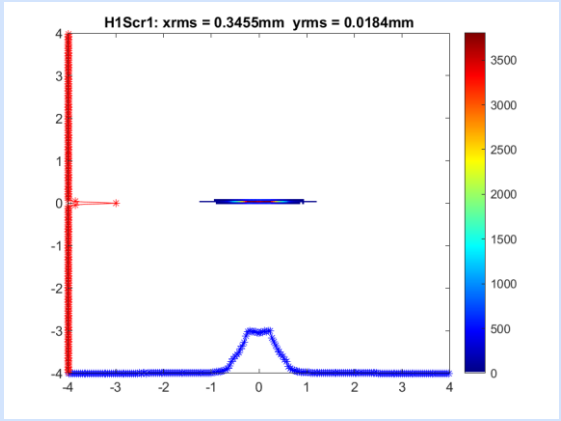
Comparing PP beamlet with VPP beamlet

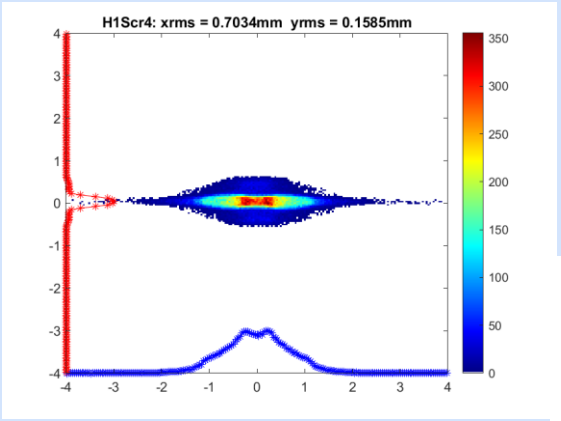
Result of passing beam through a hole

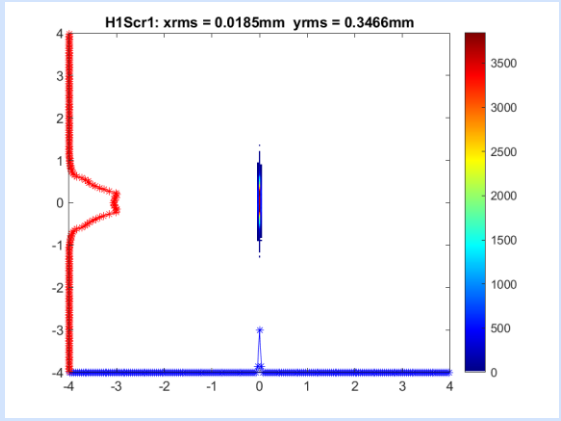


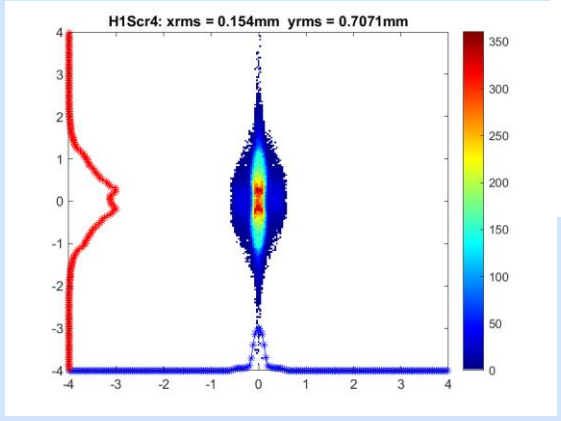


Result of crossing horizontal and vertical beamlets

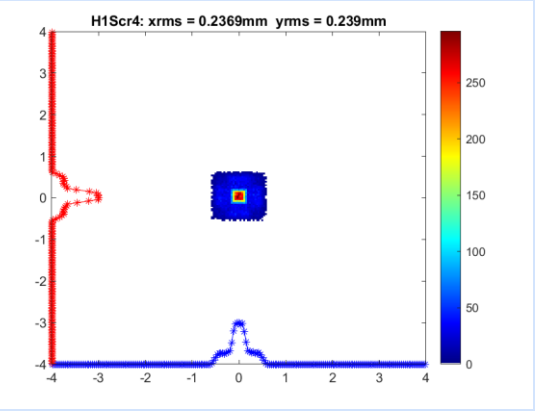








Getting rid of the foreign particles → Minimum of crossed beamlets

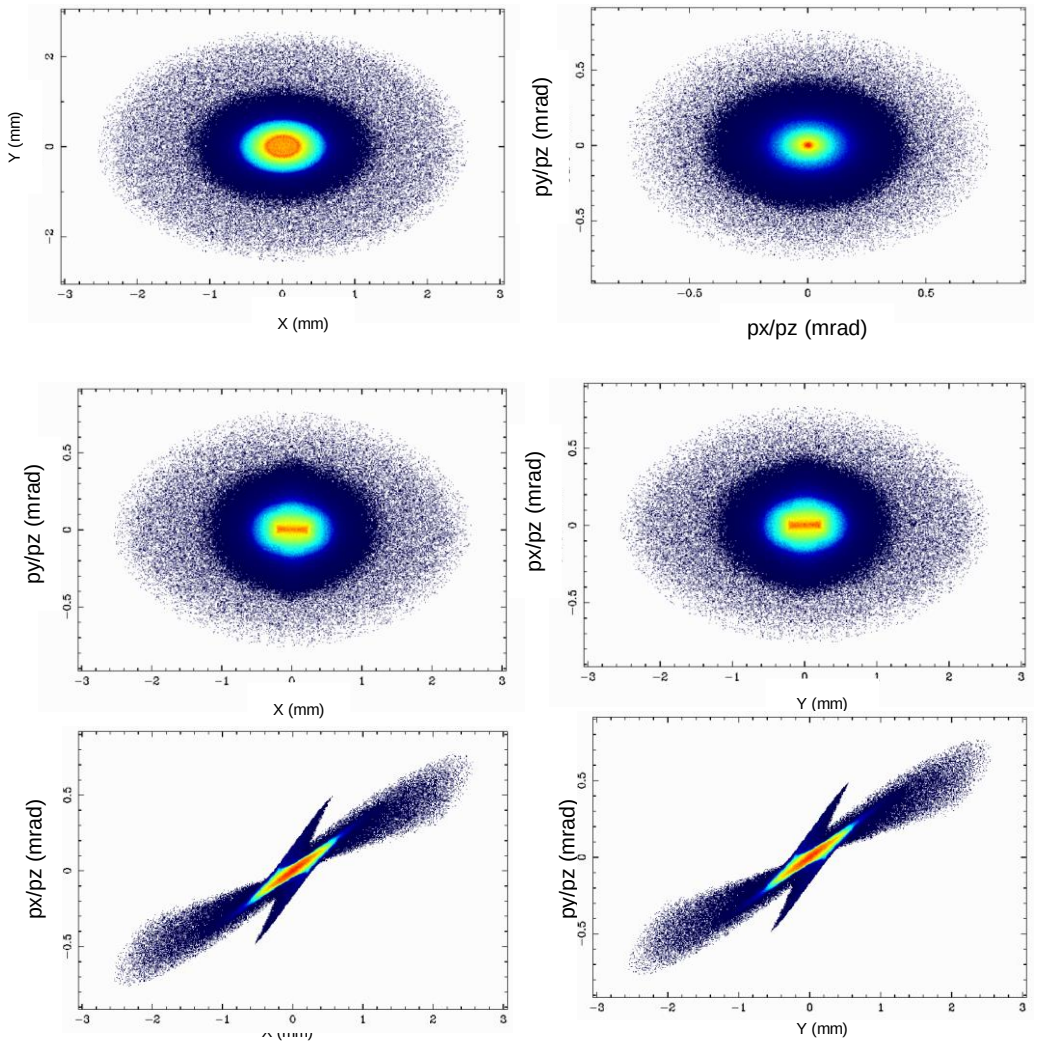


Astra Beam (uncoupled)

Results from Astra monitor (post-pro)

- ASTRA beam generated from 6 ps FWHM temporal gaussian laser

Particles taken into account	N =	2000000	
total charge	Q =	-0.2500	nC
horizontal beam position	x =	-9.3116E-06	mm
vertical beam position	y =	-5.3608E-07	mm
longitudinal beam position	z =	5.280	m
horizontal beam size	sig x =	0.3699	mm
vertical beam size	sig y =	0.3698	mm
longitudinal beam size	sig z =	1.047	mm
average kinetic energy	E =	18.78	MeV
energy spread	dE =	49.43	keV
average momentum	P =	19.29	MeV/c
transverse beam emittance	eps x =	0.6068	pi mrad mm
correlated divergence	cor x =	0.1146	mrad
transverse beam emittance	eps y =	0.6067	pi mrad mm
correlated divergence	cor y =	0.1146	mrad
longitudinal beam emittance	eps z =	12.62	pi keV mm
correlated energy spread	cor z =	47.94	keV
emittance ratio eps y/eps x	=	1.000	
trace space emittance	eps x =	0.6069	pi mrad mm
trace space emittance	eps y =	0.6069	pi mrad mm
Reduced emittances:			
hor. emittance minus z correlation:	=	0.6011	pi mrad mm
hor. emittance minus z & E correlation:	=	0.6063	pi mrad mm
ver. emittance minus z correlation:	=	0.6010	pi mrad mm
ver. emittance minus z & E correlation:	=	0.6062	pi mrad mm
long. emitance minus 2nd order corr.:	=	5.513	pi keV mm
long. emitance minus 2nd & 3rd order corr.:	=	4.781	pi keV mm



Astra Beam (uncoupled)

Results from slit scan files and VPP algorithm

- Astra Results
  - ϵ_x = 0.6069 mm mrad
  - ϵ_y = 0.6069 mm mrad
- Slit scan files
  - scan step = 10um approximately (520 beamlets)
  - x and y beamlets, slit positions, must haves
- VPP beamlets
  - crossing every 6th beamlets (Huge data of images!!)
- Relative error = $\frac{\epsilon_{astra} - \epsilon_{slit_{scan/vpp}}}{\epsilon_{astra}}$

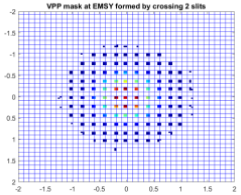
Slit width (um)	Slit scan emittance (mm mrad)				VPP emittance (mm mrad)			
	ϵ_x	ϵ_y	ϵ_x rel. err %	ϵ_y rel. err %	ϵ_x	ϵ_y	ϵ_x rel. err %	ϵ_y rel. err %
50	0.6229	0.6229	2.63	2.63	0.7236	0.7152	19	17.8
10	0.6098	0.6101	0.48	0.53	0.5541	0.5893	8.6	2.9

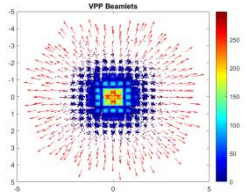
VPP Algorithm – overestimating? underestimating?

Exploring further: Estimating mean and variance

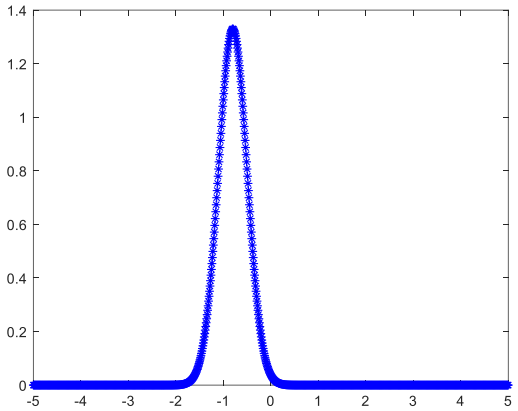
- x= -5 : **step** : 5
- **mu = -0.8**
- sigma = 0.3
- **var = 0.09**
- G = 1/sqrt(2*pi)*((1/sigma)*(exp(-0.5*((x-mu)/sigma).^2)))
- G1 = G/sum(G)
- meanG=sum(x.*G1)
- varG= sum(G1.*(meanG -x).^2)

- **PP Emsy subimages case**
- **PP beamlets crossed at edges**

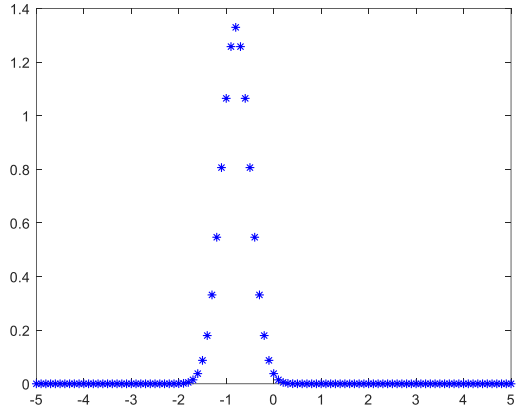




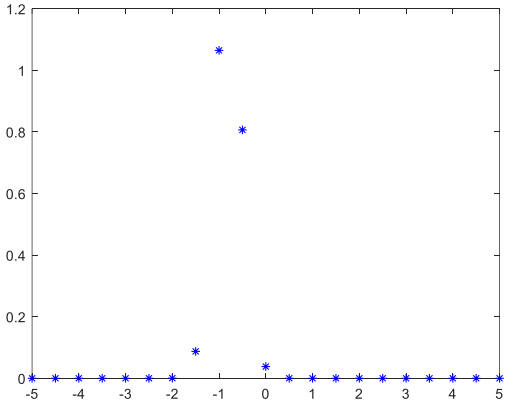
step = 0.01, mu = -0.8, var = 0.09



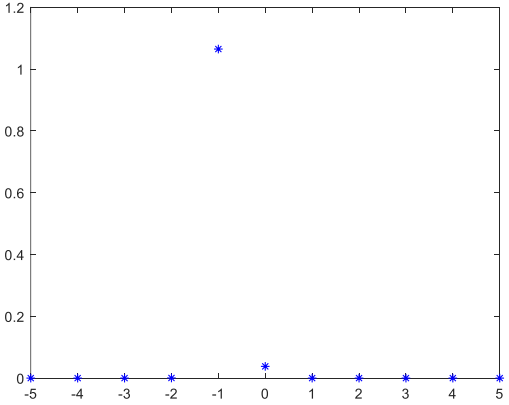
step = 0.1, mu = -0.8, var = 0.09



step = 0.5, mu = -0.8011, var = 0.0917



step = 1, mu = -0.966, var = 0.0337

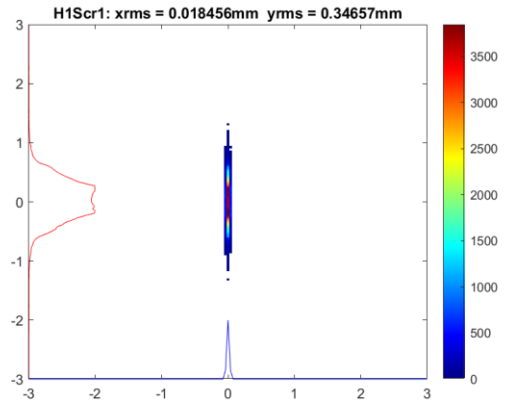


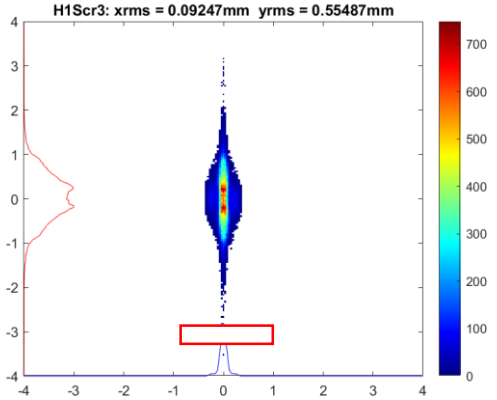
Dependent on resolution of camera!

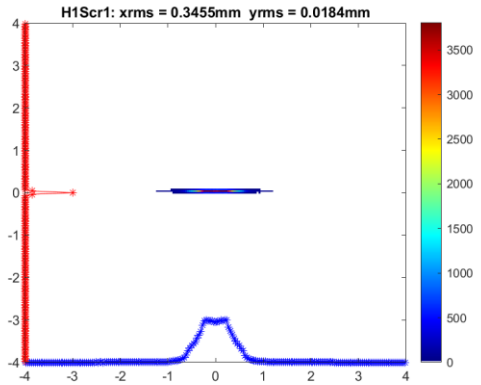
VPP Proof of Principle simulation

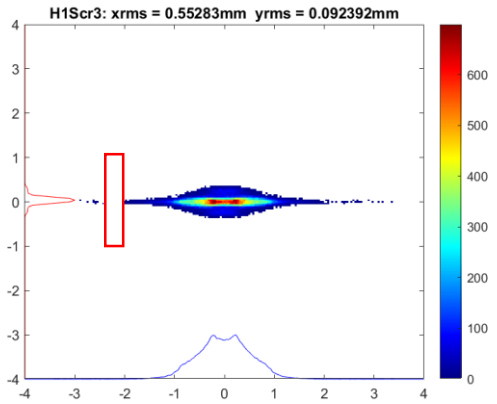
Emittance Results of slit scan

- EMSY1X central beamlet + EMSY2Y scan + H1Scr4
- EMSY1Y central beamlet + EMSY2X scan + H1Scr4









EMSY1 slit width (um)	EMSY2 slit width (um)	Slit scan emittance (mm mrad)	
		ϵ_x	ϵ_y
50	50	0.8435	-
		-	0.8471
	10	0.7900	-
		-	0.7921

```
L1= 1848 % distance between EMSY1 and EMSY2  7125-5277
L2= 1795 % distance between EMSY2 and H1Scr5 8920-7125
L3= 3133 % distance between EMSY1 and H1Scr4 8410-5277
L4= 3643 % distance between EMSY1 and H1Scr5 8920-5277
L5= 1285 % distance between EMSY2 and H1Scr4 8410-7125
L6= 5153 % distance between EMSY2 and Pst.Scr1 12278-7125
```

Drift length less < 3.133

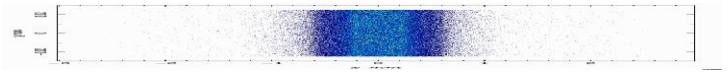
➢ **Check it for greater drift length**

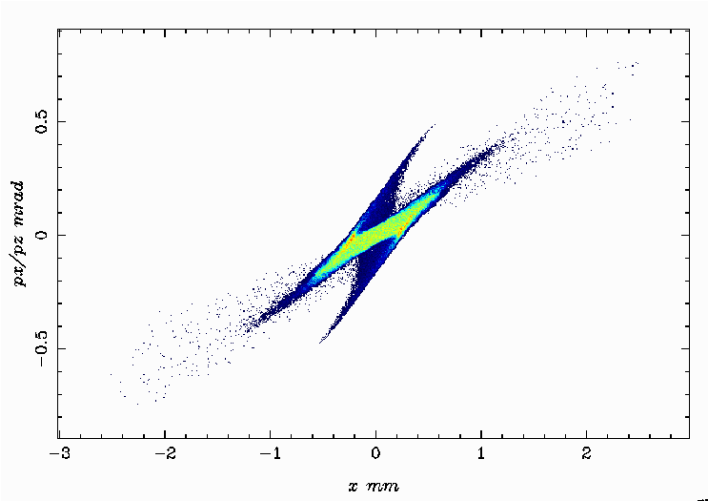
VPP Proof of Principle simulation

Astra monitor

```
Particles taken into account      N =     116382
total charge                      Q =   -1.4548E-02 nC
horizontal beam position          x =   -7.7091E-04 mm
vertical beam position            y =    4.2133E-06 mm
longitudinal beam position        z =     5.280     m
horizontal beam size          sig x =     0.3453    mm
vertical beam size            sig y =     1.4418E-02 mm
longitudinal beam size        sig z =     0.9072    mm
average kinetic energy            E =     18.79     MeV
energy spread                    dE =     42.95     keV
average momentum                  P =     19.29     MeV/c
transverse beam emittance     eps x =     0.7669    pi mrad mm
correlated divergence         cor x =     0.1063    mrad
transverse beam emittance     eps y =     2.6209E-02 pi mrad mm
correlated divergence         cor y =     4.1692E-03 mrad
longitudinal beam emittance   eps z =     7.933     pi keV mm
correlated energy spread      cor z =     42.05     keV
emittance ratio eps y/eps x       =     29.26

trace space emittance         eps x =     0.7668    pi mrad mm
trace space emittance         eps y =     2.6197E-02 pi mrad mm
Reduced emittances:
hor. emittance minus z correlation:          =     0.7644     pi mrad mm
hor. emittance minus z & E correlation:      =     0.7648     pi mrad mm
ver. emittance minus z correlation:          =     2.6209E-02 pi mrad mm
ver. emittance minus z & E correlation:      =     2.6209E-02 pi mrad mm
long. emitance minus 2nd order corr.:        =      2.707     pi keV mm
long. emitance minus 2nd & 3rd order corr.: =      2.656     pi keV mm
```



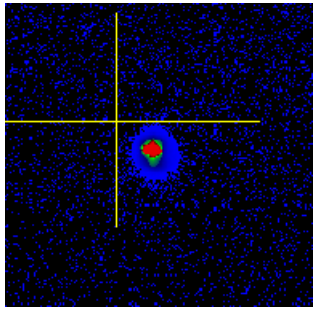


VPP Proof of Principle experiment

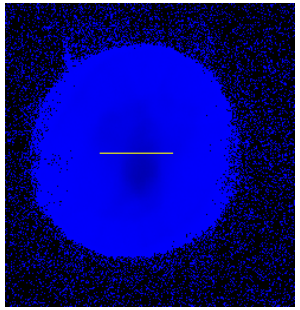
Experiment in shifts 12-14.02.2021 (~2 shifts)

- Laser : MBI
- Beam charge : 250pC
- Beam energy: 21 MeV/c
- Solenoid scan at EMSY2 using Pst.Scr1 as MOI screen
- Set Imain corresponding to minimum projected emittance
- EMSY2Y scan for 5 beamlets from EMSY1X at different locations
- EMSY2X scan for 5 beamlets from EMSY1Y at different locations
- Scanned without Gun Quads
- Scanned with Gun Quads 1 and 2

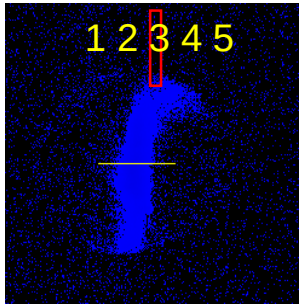
Full Beam at H1Scr3



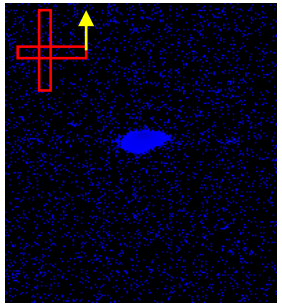
Full Beam transported to PstScr1



Beamlet at PstScr1 after EMSY1X slit

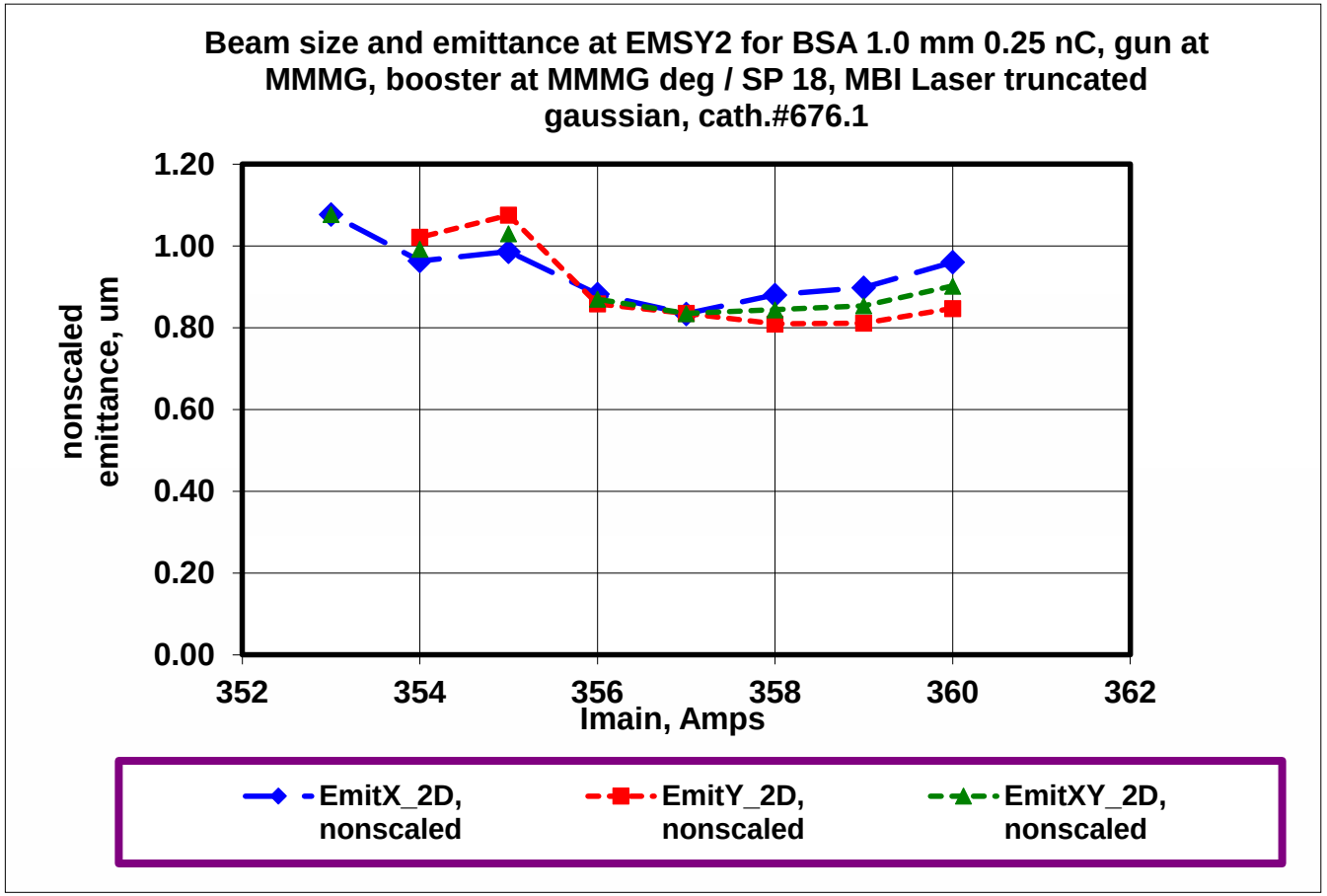


Beamlet at PstScr1 after EMSY2Y slit



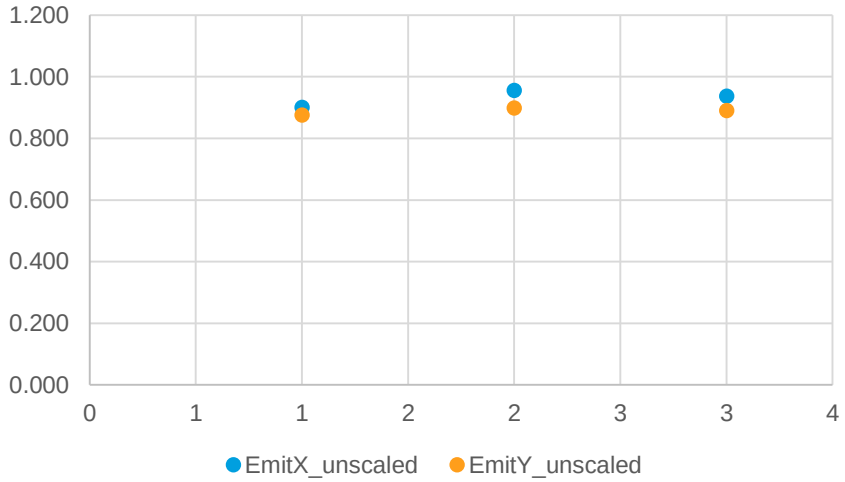
Experiment

Solenoid scan at EMSY2

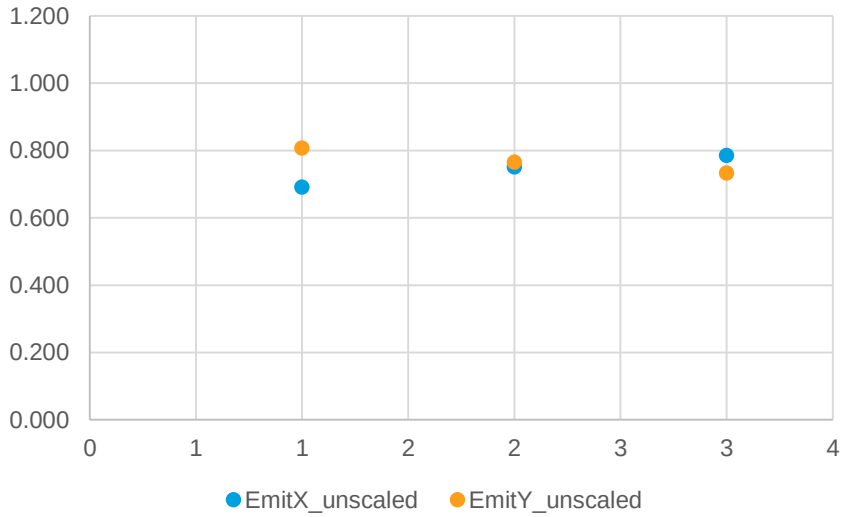


Statistics at Imain = 357 A

Without Gun Quads



With Gun Quads Q1+Q2

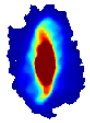


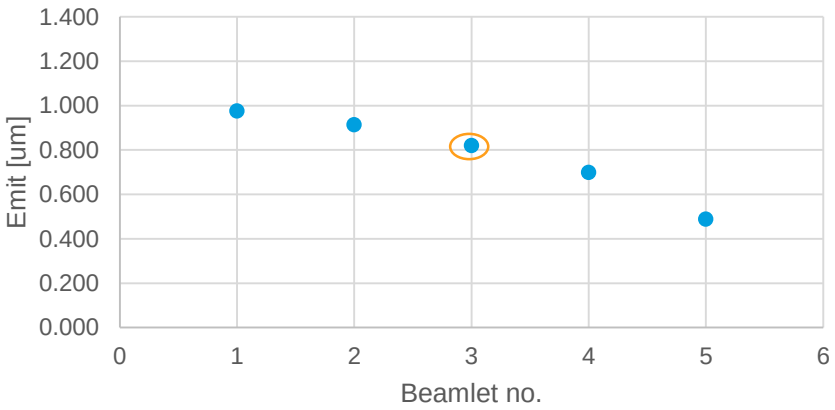
Experiment

Emittance for 5 beamlets in X and 5 in Y

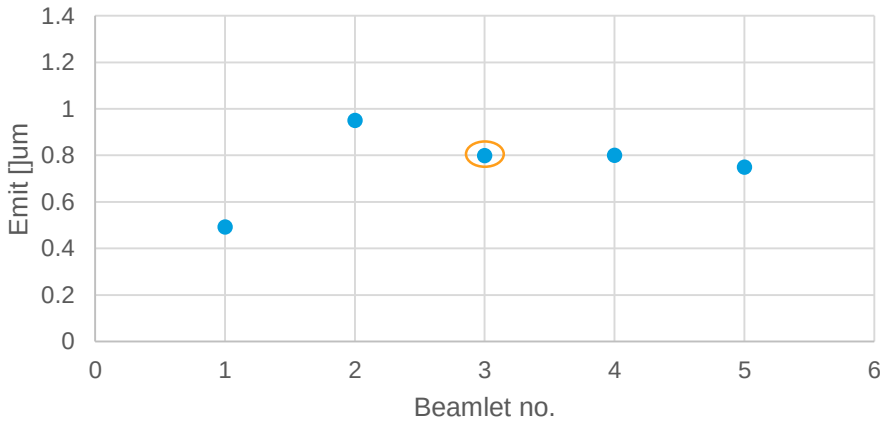
Without statistics!

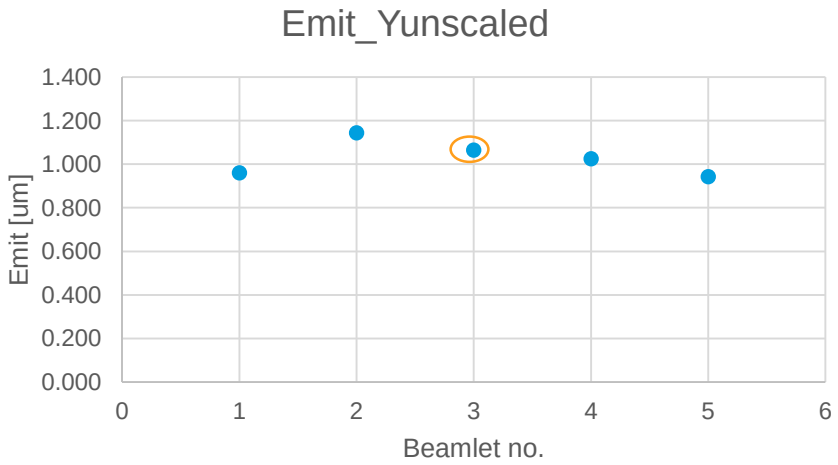
Without Gun Quads

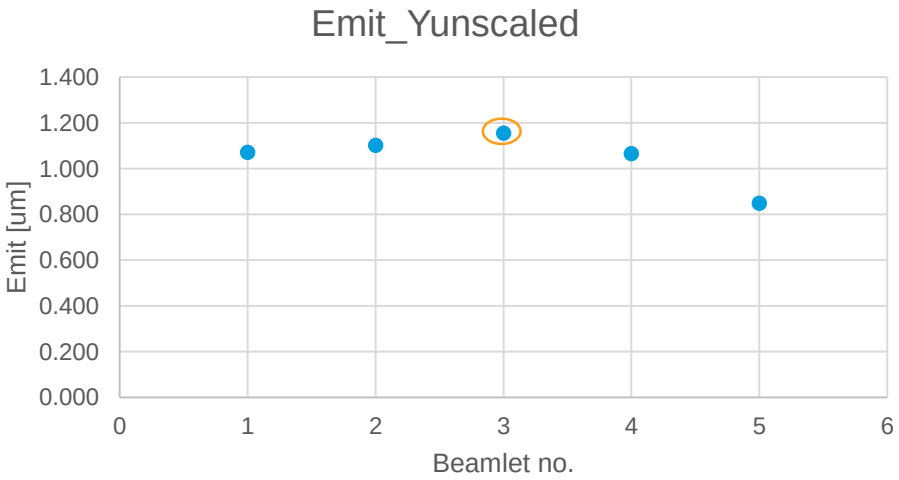




With Gun Quads Q1+Q2

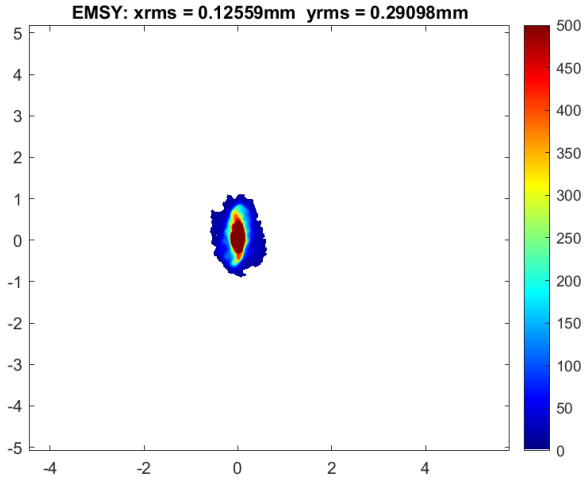


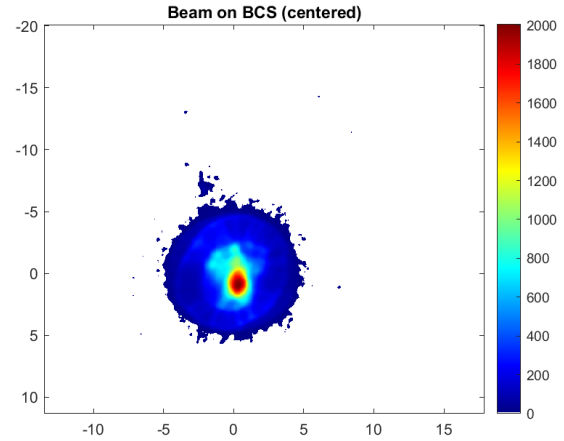




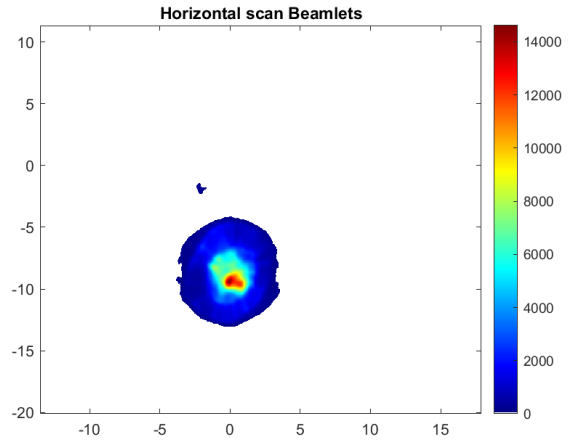
Experimental data without gun quads

Emittance at EMSY2 with Pst.Scr1 as observation screen



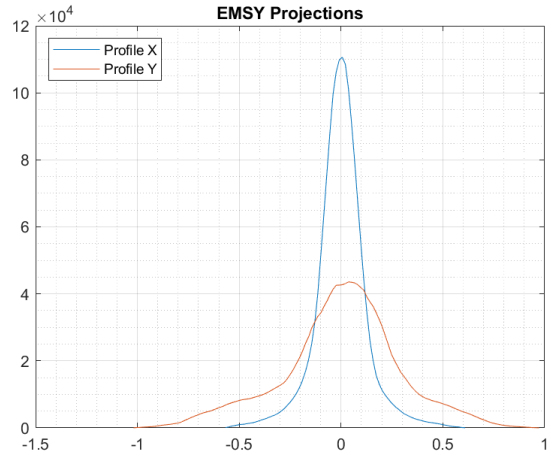


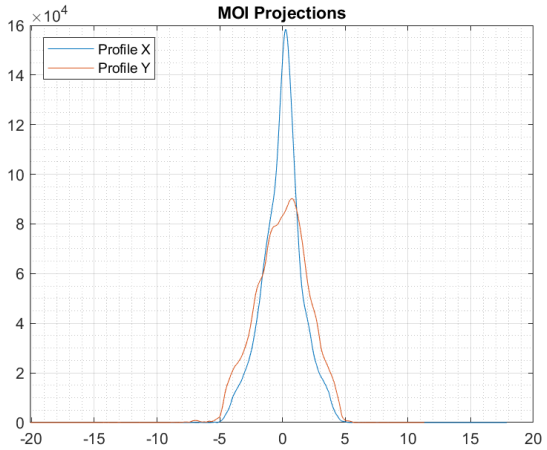
Summing beamlets

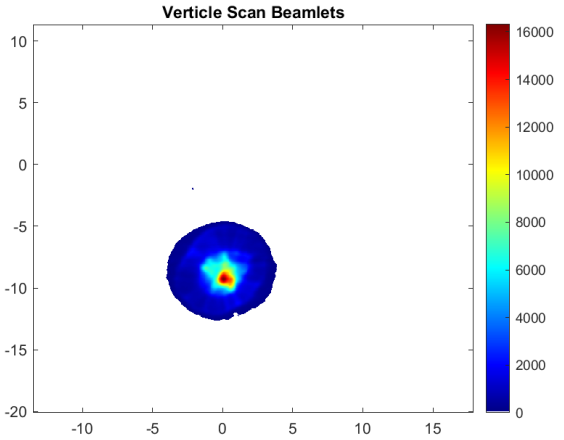


Number of beamlets X = 110

Number of beamlets Y = 125







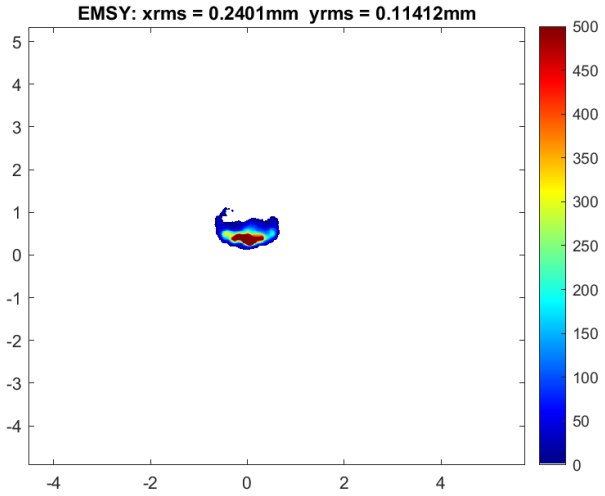
Slit scan

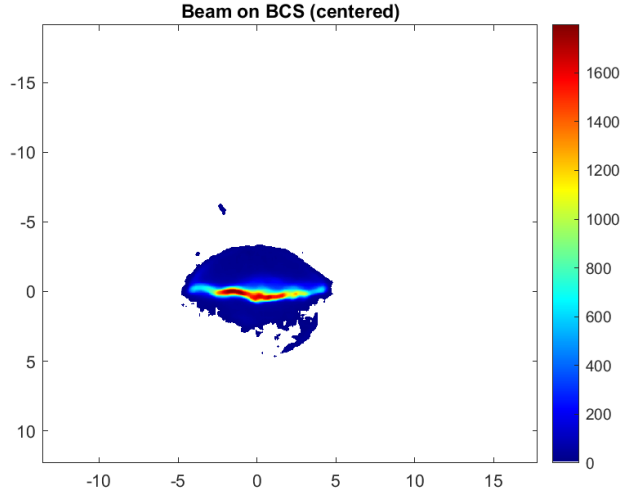
$\epsilon_x = 0.7348$

$\epsilon_y = 0.8406$

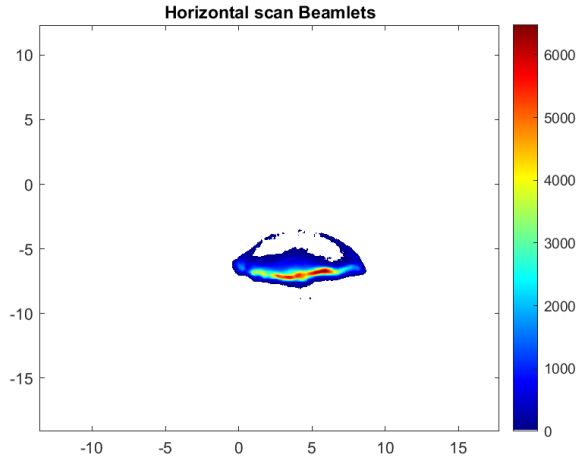
Experimental data without gun quads

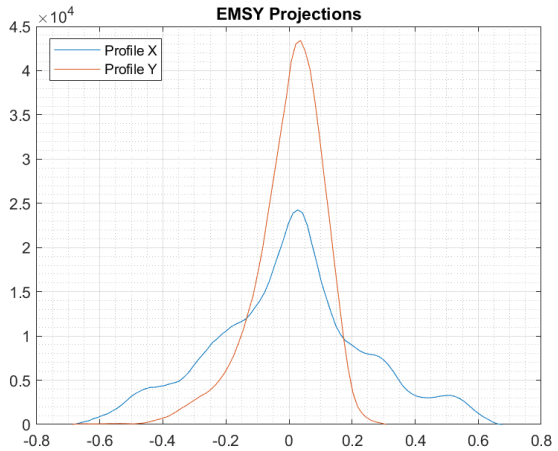
EMSY1Y central beamlet +EMSY2X scan +Pst.Scr1

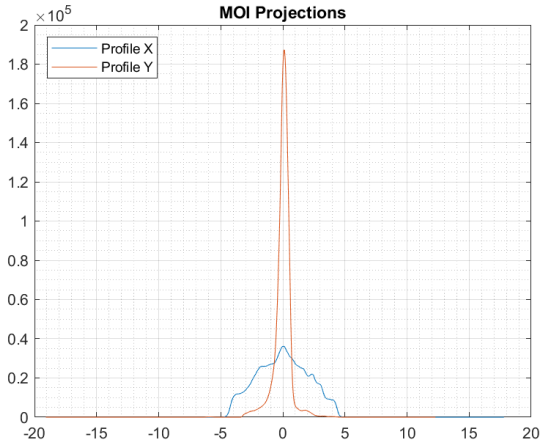


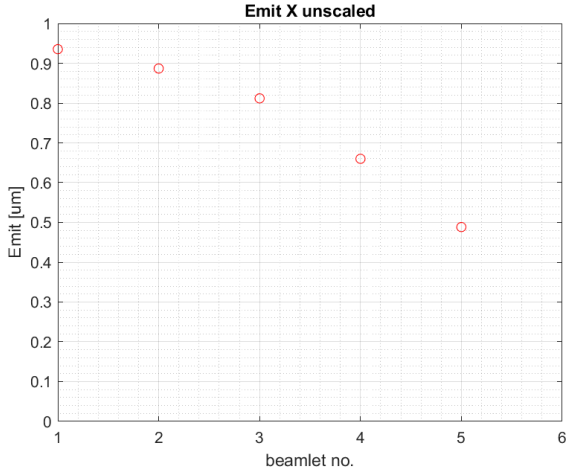


Summing beamlets



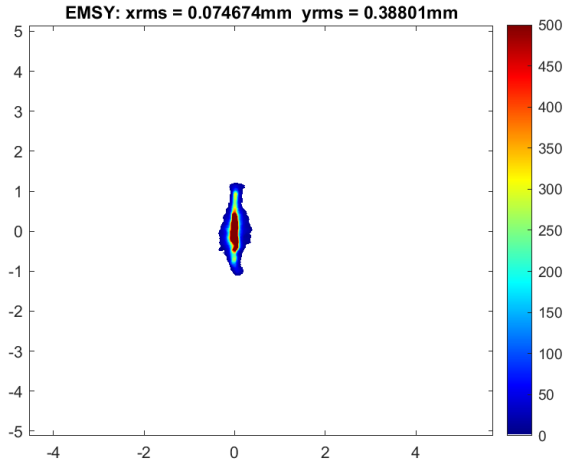


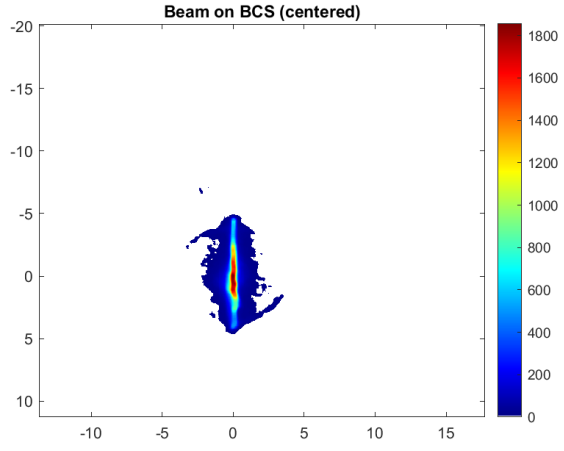




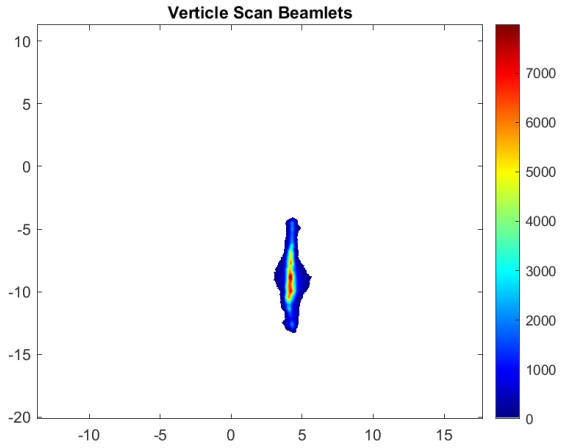
Experimental data without gun quads

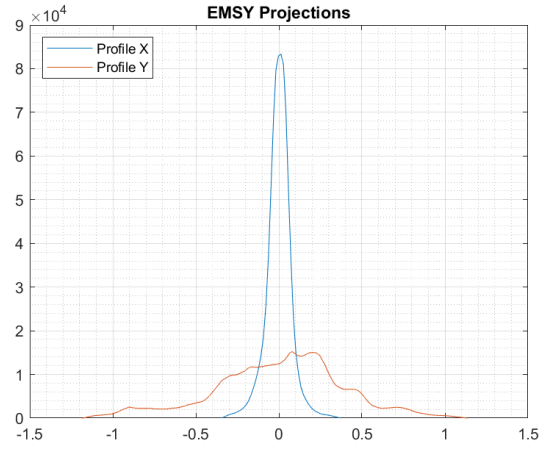
EMSY1X central beamlet + EMSY2Y scan + Pst.Scr1

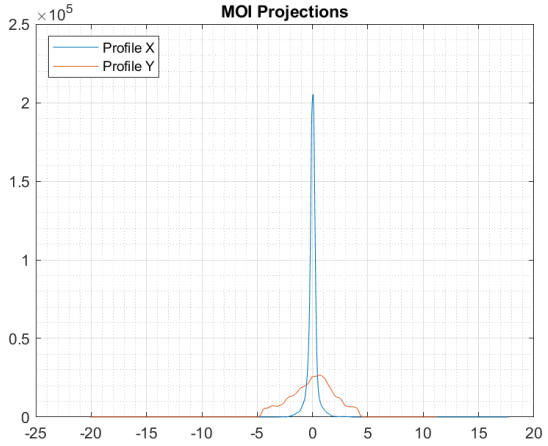


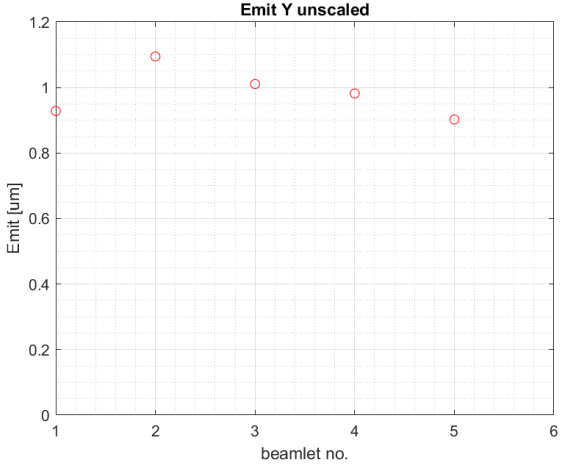


Summing beamlets



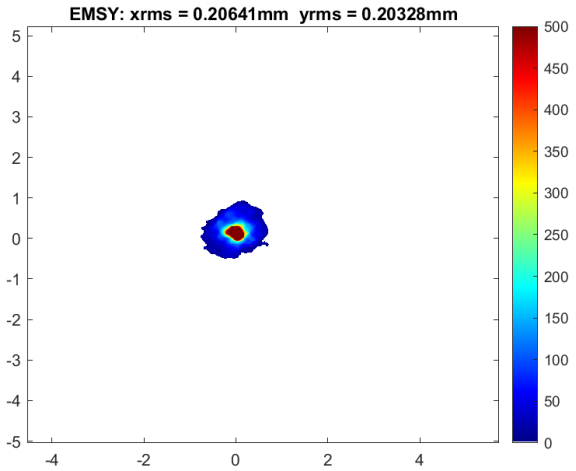


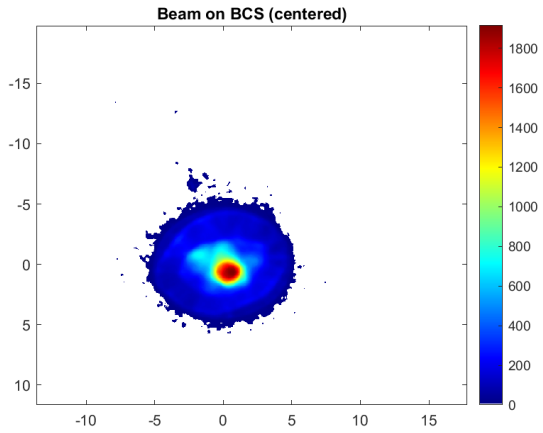




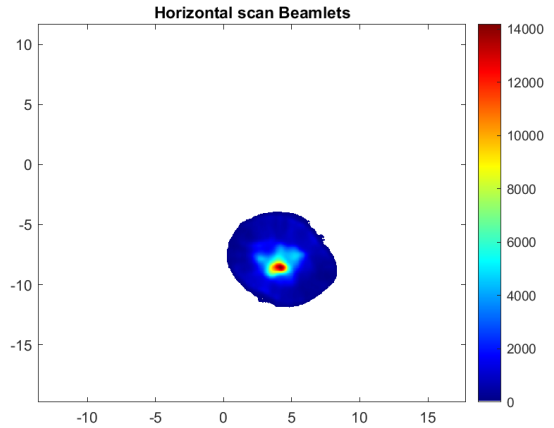
Experimental data with gun quads

Emittance at EMSY2 with Pst.Scr1 as observation screen



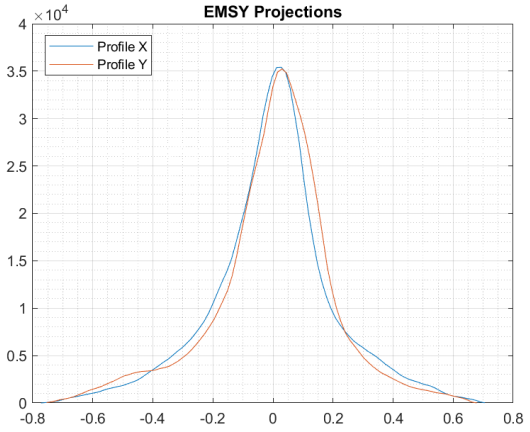


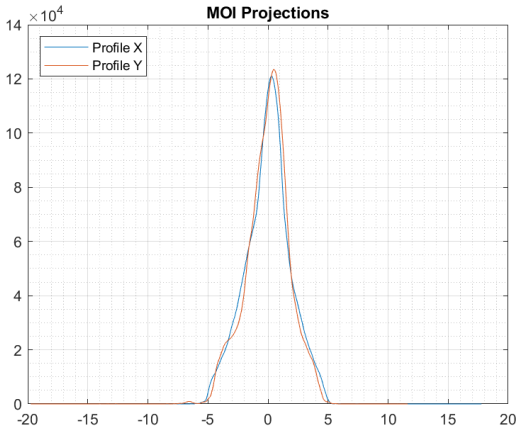
Summing beamlets

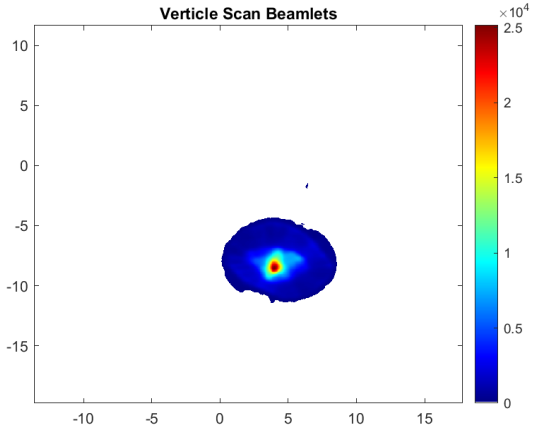


Number of beamlets X = 220

Number of beamlets Y = 250







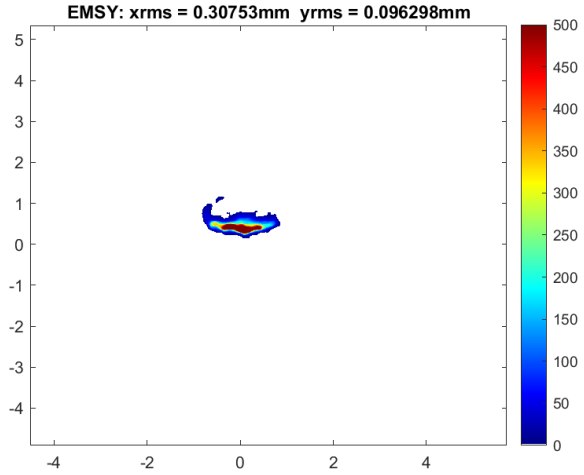
Slit scan

$\epsilon_x = 0.7607$

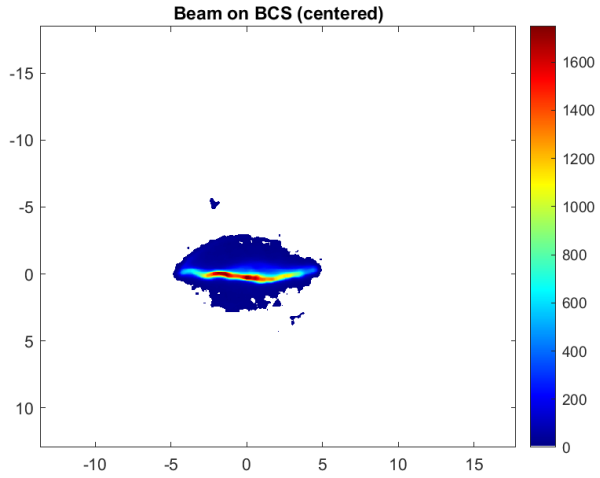
$\epsilon_y = 0.7386$

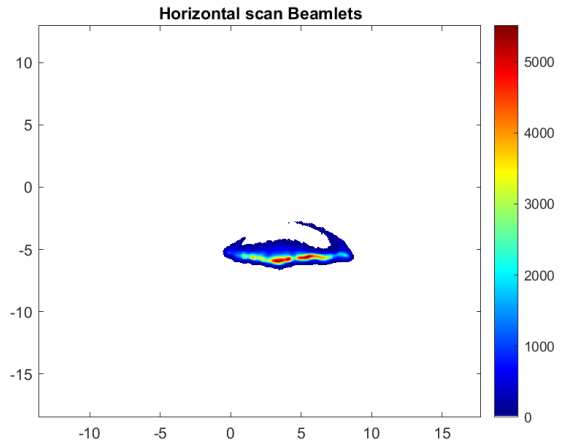
Experimental data with gun quads

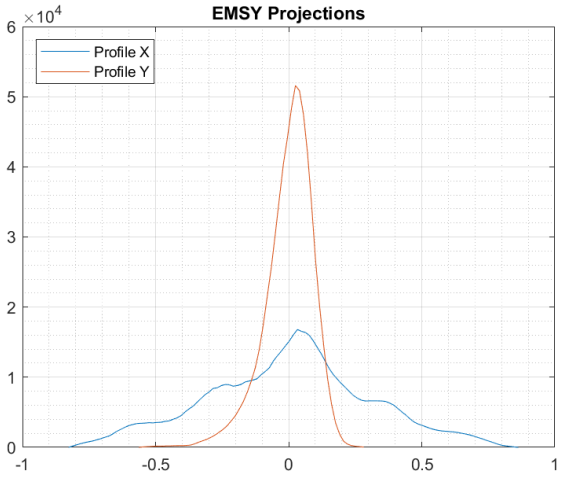
EMSY1Y central beamlet +EMSY2X scan +Pst.Scr1

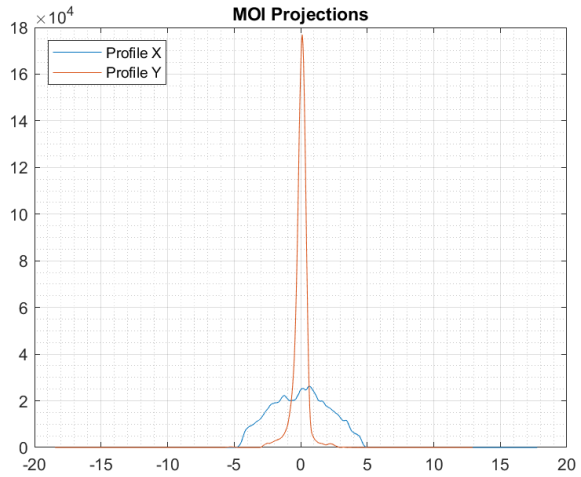


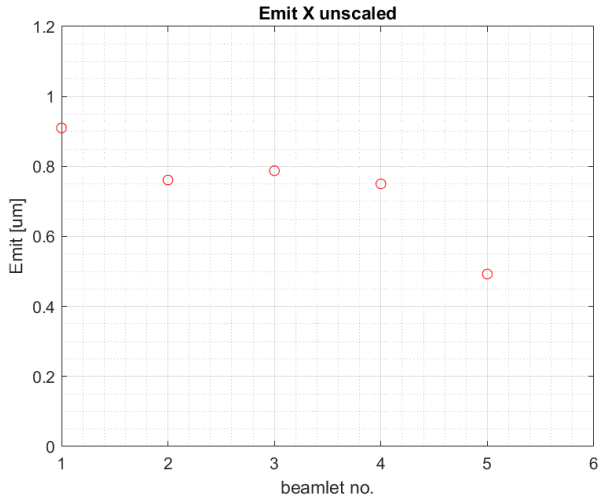
Summing beamlets





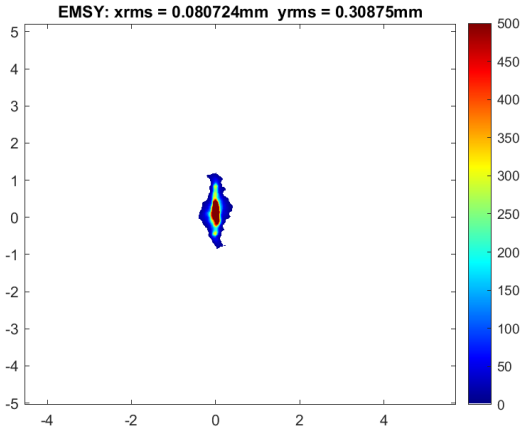


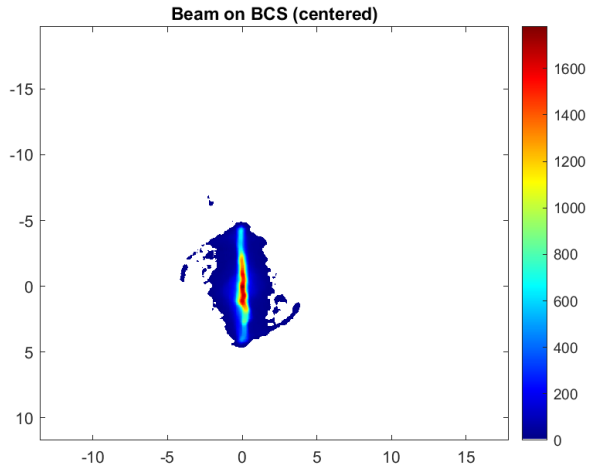




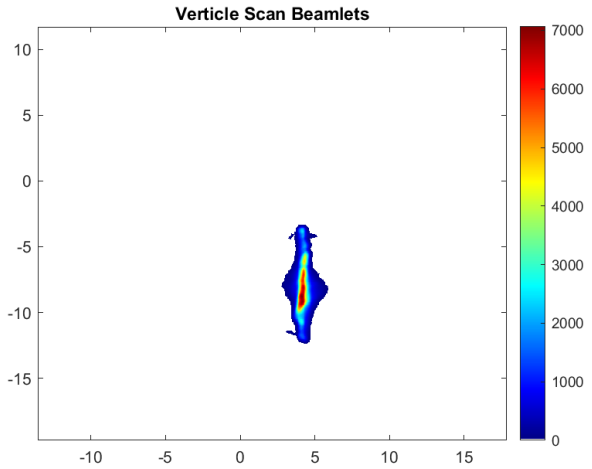
Experimental data with gun quads

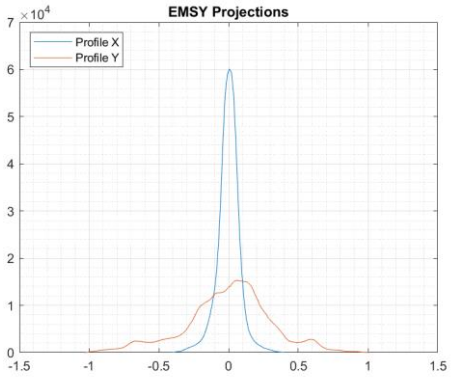
EMSY1X central beamlet +EMSY2Y scan +Pst.Scr1

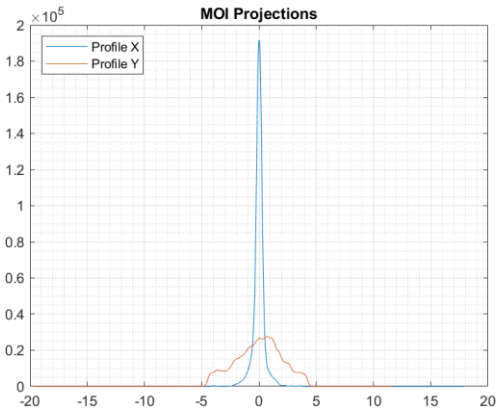


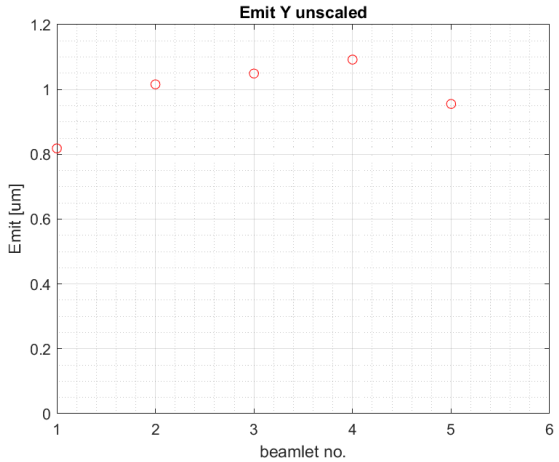


Summing beamlets









Analysis & Outlook

Further Analysis and Data taking

- Foreign particles effect
- Slightly higher emittance for non-central beamlets
- Simulation of non-central beamlets
- More experimental data?
- Using SlitScanner.m using a stop-n-go procedure and do Nemsy1x x Nemsy2y and Nemsy1y x Nemsy2x scans with it.