Intensity control and diagnostic by Compton scattering

Work partially supported by the
European Union's H2020 Framework
Programme under grant agreement no.
951754 (FCCIS).

WEPOST010

Controlling e⁺e⁻ Circular Collider Bunch Intensity by Laser Compton Scattering

F. Zimmermann, CERN, Geneva, Switzerland
T.O. Raubenheimer, SLAC & Stanford U., U.S.A.

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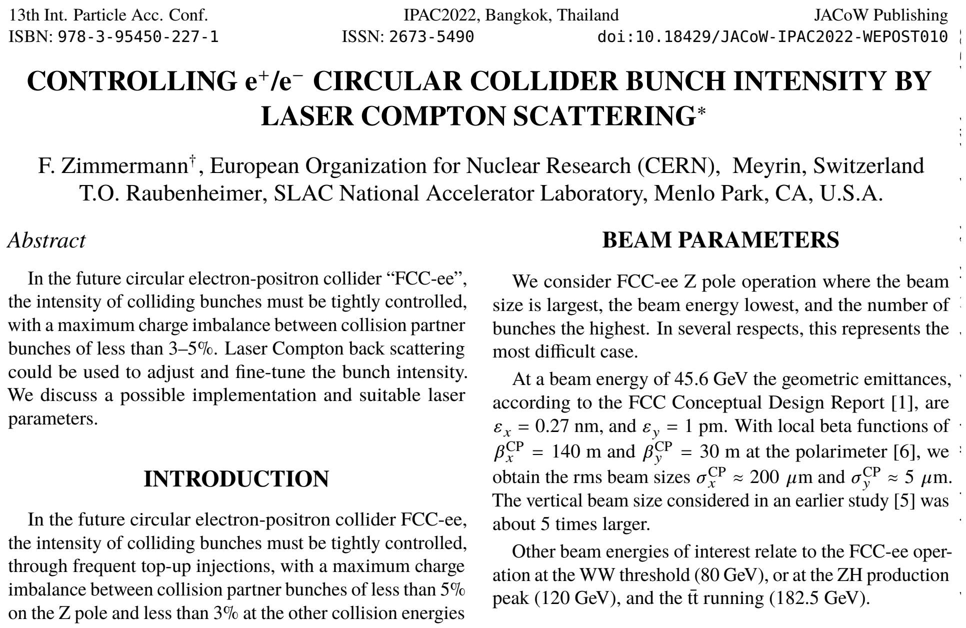


13th Int. Particle Acc. Conf. IPAC2022, Bangkok, Thailand JACoW Publishing
ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-WEPOST010

CONTROLLING e$^+$/e$^-$ CIRCULAR COLLIDER BUNCH INTENSITY BY LASER COMPTON SCATTERING*

F. Zimmermann†, European Organization for Nuclear Research (CERN), Meyrin, Switzerland
T.O. Raubenheimer, SLAC National Accelerator Laboratory, Menlo Park, CA, U.S.A.

Abstract

In the future circular electron-positron collider “FCC-ee”, the intensity of colliding bunches must be tightly controlled, with a maximum charge imbalance between collision partner bunches of less than 3–5%. Laser Compton back scattering could be used to adjust and fine-tune the bunch intensity. We discuss a possible implementation and suitable laser parameters.

INTRODUCTION

In the future circular electron-positron collider FCC-ee, the intensity of colliding bunches must be tightly controlled, through frequent top-up injections, with a maximum charge imbalance between collision partner bunches of less than 5% on the Z pole and less than 3% at the other collision energies

BEAM PARAMETERS

We consider FCC-ee Z pole operation where the beam size is largest, the beam energy lowest, and the number of bunches the highest. In several respects, this represents the most difficult case.

At a beam energy of 45.6 GeV the geometric emittances, according to the FCC Conceptual Design Report [1], are $\varepsilon_x = 0.27$ nm, and $\varepsilon_y = 1$ pm. With local beta functions of $\beta_x^{\rm CP} = 140$ m and $\beta_y^{\rm CP} = 30$ m at the polarimeter [6], we obtain the rms beam sizes $\sigma_x^{\rm CP} \approx 200\ \mu$m and $\sigma_y^{\rm CP} \approx 5\ \mu$m. The vertical beam size considered in an earlier study [5] was about 5 times larger.

Other beam energies of interest relate to the FCC-ee operation at the WW threshold (80 GeV), or at the ZH production peak (120 GeV), and the $t\bar{t}$ running (182.5 GeV).

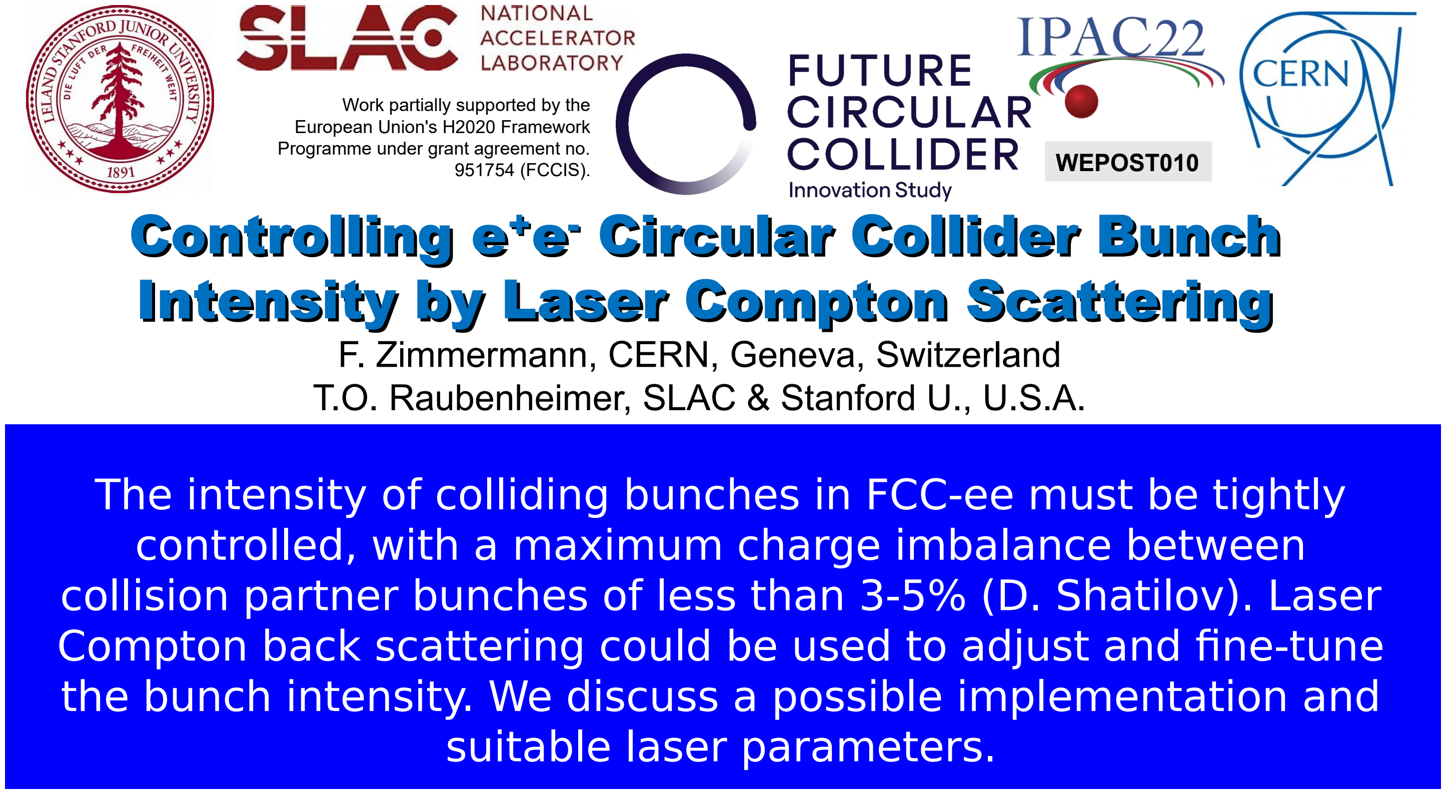
INFN
MILANO

Intensity control and diagnostic by Compton scattering

In two ~~worlds~~ lines:

Due to Flip-Flop instability charge of bunches bust be the same (max imbalance 3-5%)

We should find method of control intensity. To do this was proposed Compton scattering.



SLAC NATIONAL ACCELERATOR LABORATORY

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FUTURE CIRCULAR COLLIDER
Innovation Study

IPAC22

WEPOST010

CERN

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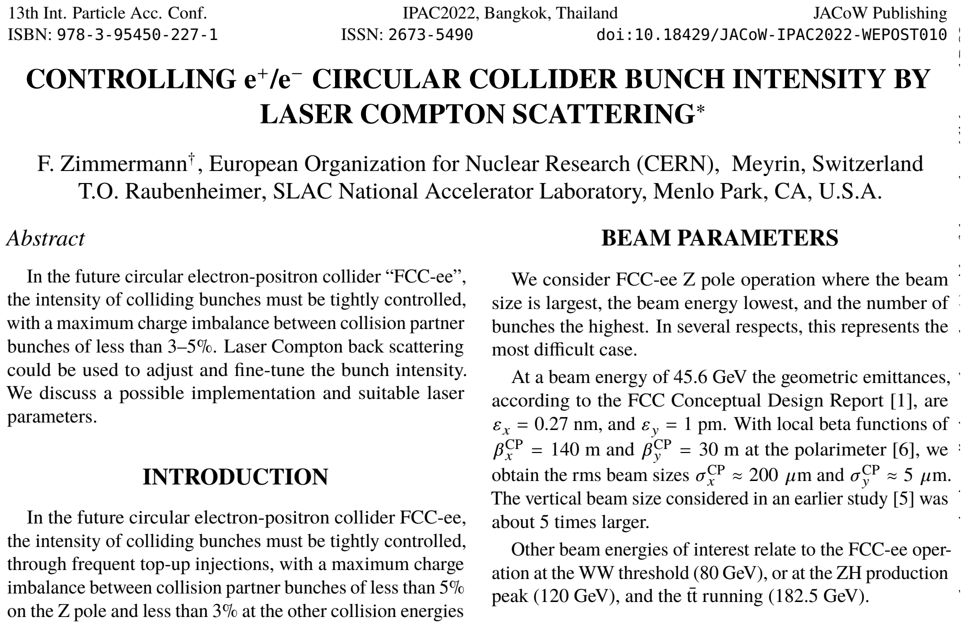

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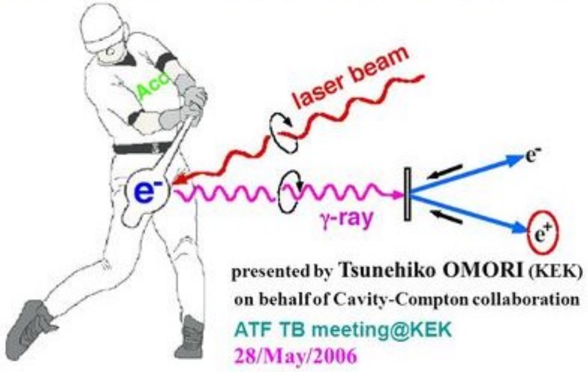


presented by Tsunehiko OMORI (KEK)
on behalf of Cavity-Compton collaboration
ATF TB meeting@KEK
28/May/2006

$$E_{phot} \sim 4\gamma^2 E_{las}$$

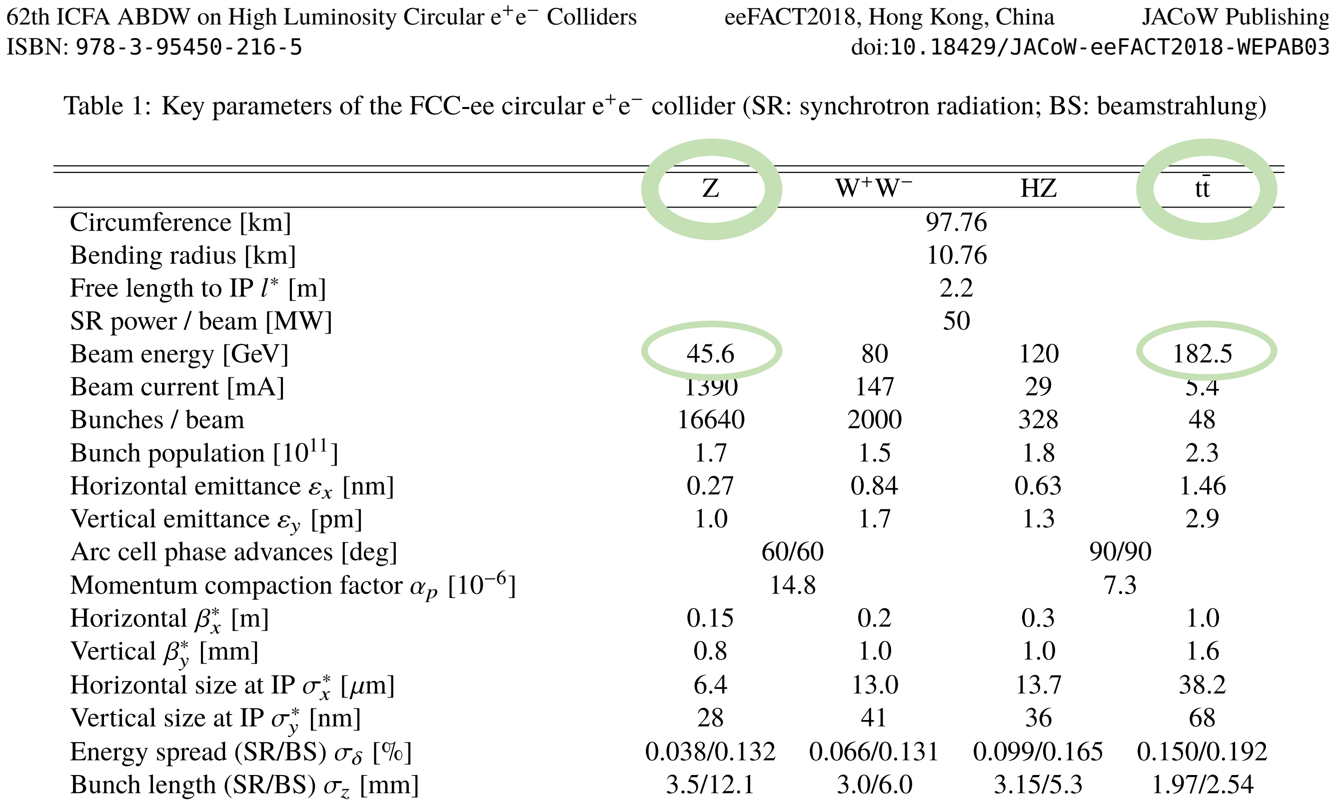
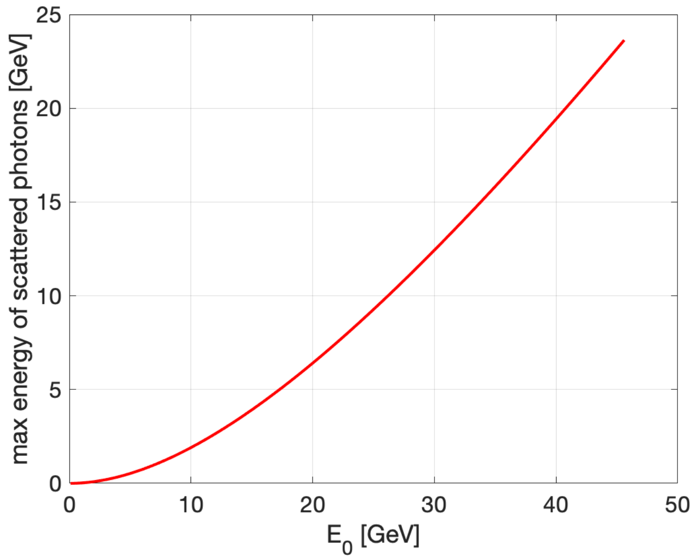

62th ICFA ABDW on High Luminosity Circular e^+e^- Colliders eeFACT2018, Hong Kong, China JACoW Publishing
ISBN: 978-3-95450-216-5 doi:10.18429/JACoW-eeFACT2018-WEPAB03

Table 1: Key parameters of the FCC-ee circular e^+e^- collider (SR: synchrotron radiation; BS: beamstrahlung)

	Z	W^+W^-	HZ	$t\bar{t}$
Circumference [km]	97.76			
Bending radius [km]	10.76			
Free length to IP l^* [m]	2.2			
SR power / beam [MW]	50			
Beam energy [GeV]	45.6	80	120	182.5
Beam current [mA]	1390	147	29	5.4
Bunches / beam	16640	2000	328	48
Bunch population [10^{11}]	1.7	1.5	1.8	2.3
Horizontal emittance ε_x [nm]	0.27	0.84	0.63	1.46
Vertical emittance ε_y [pm]	1.0	1.7	1.3	2.9
Arc cell phase advances [deg]	60/60		90/90	
Momentum compaction factor α_p [10^{-6}]	14.8		7.3	
Horizontal β_x^* [m]	0.15	0.2	0.3	1.0
Vertical β_y^* [mm]	0.8	1.0	1.0	1.6
Horizontal size at IP σ_x^* [μm]	6.4	13.0	13.7	38.2
Vertical size at IP σ_y^* [nm]	28	41	36	68
Energy spread (SR/BS) σ_δ [%]	0.038/0.132	0.066/0.131	0.099/0.165	0.150/0.192
Bunch length (SR/BS) σ_z [mm]	3.5/12.1	3.0/6.0	3.15/5.3	1.97/2.54



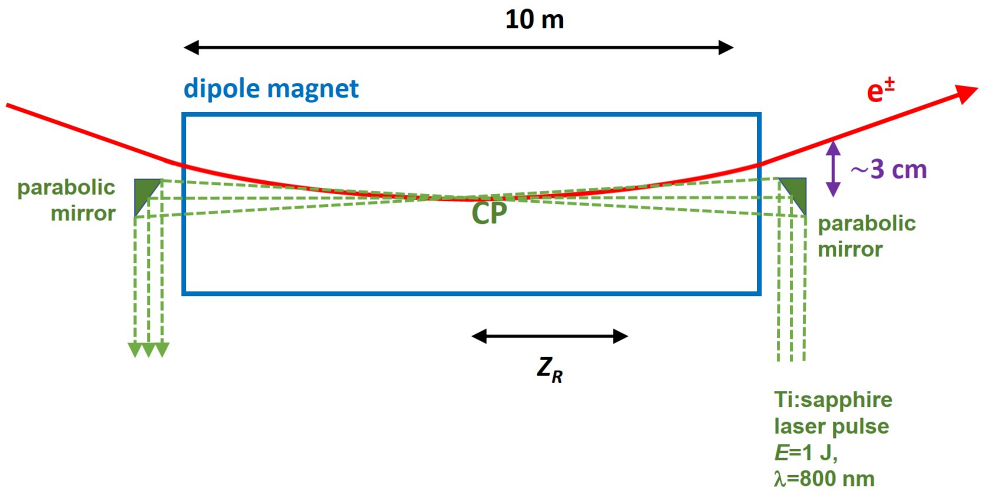
Laser	
α_0	0. [deg]
Pulse Energy	1 [J]
$\boldsymbol{\sigma}_{x,y}$	400 [μm]
λ	800 [nm]
$\boldsymbol{\sigma}_t$	300 [ps]

Beam from xsuit z

Electron beam non norm Emittances:
Emit X = 1.14249e-09
Emit Y = 1.44993e-12
Electron beam normalized Emittances:
Emit X n = 1.01942e-04
Emit Y n = 1.29374e-07

sigma_x = 3.29350e+02 [um]
sigma_y = 2.93216e+01 [um]
mean_energy = 4.55954e+04 [MeV]
std_energy = 6.42976e+01 [MeV]
energy_spread = 1.41018e-03
gamma = 8.92277e+04
delta_gamma = 1.25827e+02

NMP = 1.00000e+06
N P = 2.43331e+11
zeta = -1.34338e-07



Sketch of the Compton collision inside a single 10 m long dipole.

```
%% laser
angle_deg=0;% in degree
pulseE=1.; %laser pulse energy [J]
sigLrx=400;% given in [mu m] micro meter w0=2*sigLr;
sigLry=400;% given in [mu m] micro meter w0=2*sigLr;
laserwl=800; % laser wavelength [nm] nano meters
sigt=300.; % pulse length [ps]
STOKES=[0 0 1];% linear [0 0 1]; circular [0 1 0]
```

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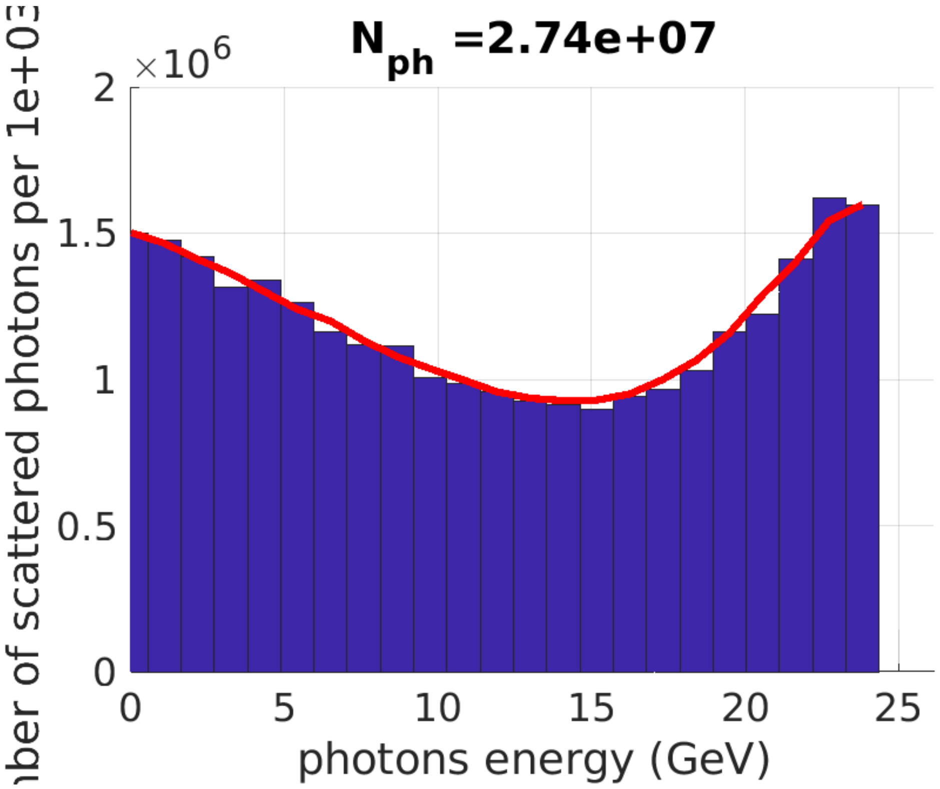
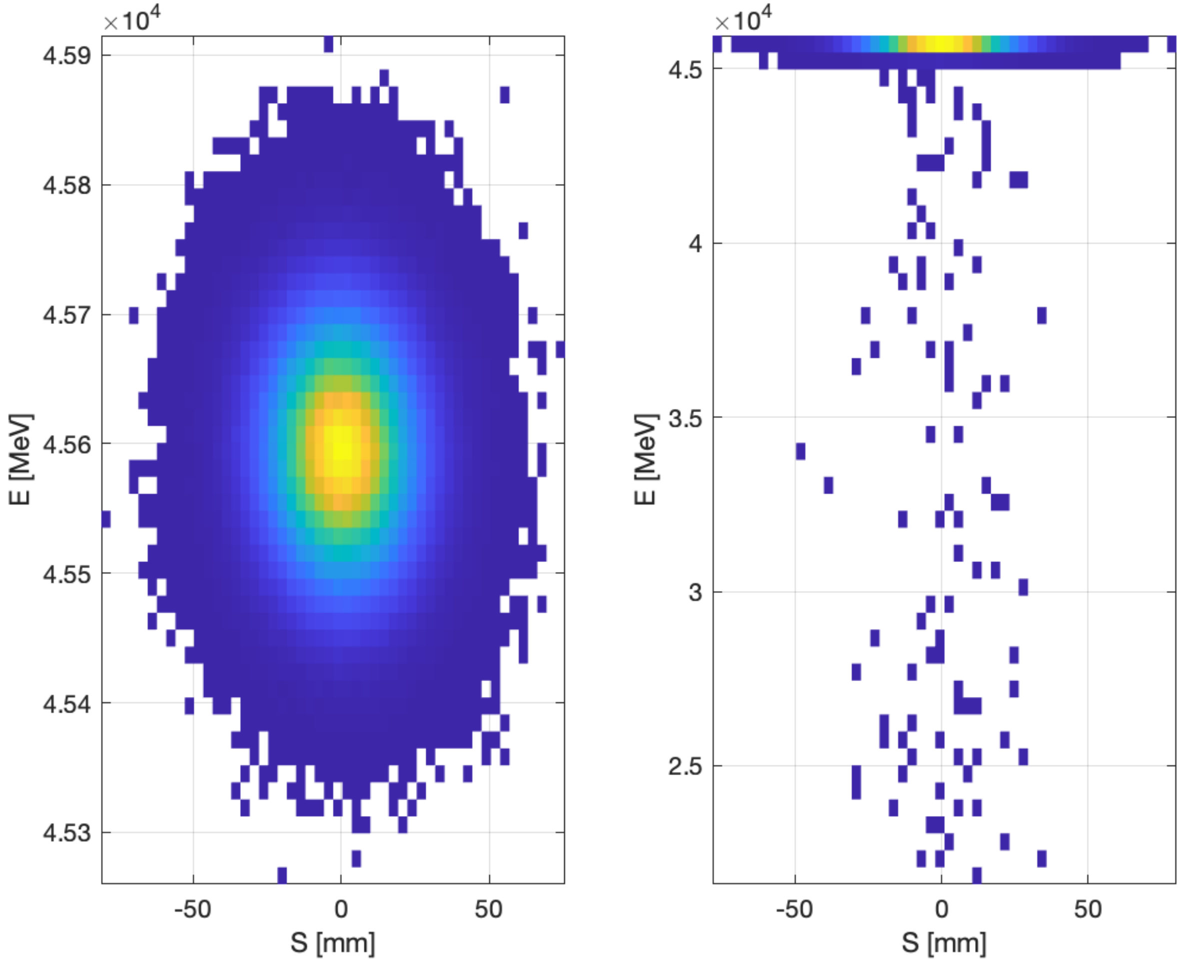
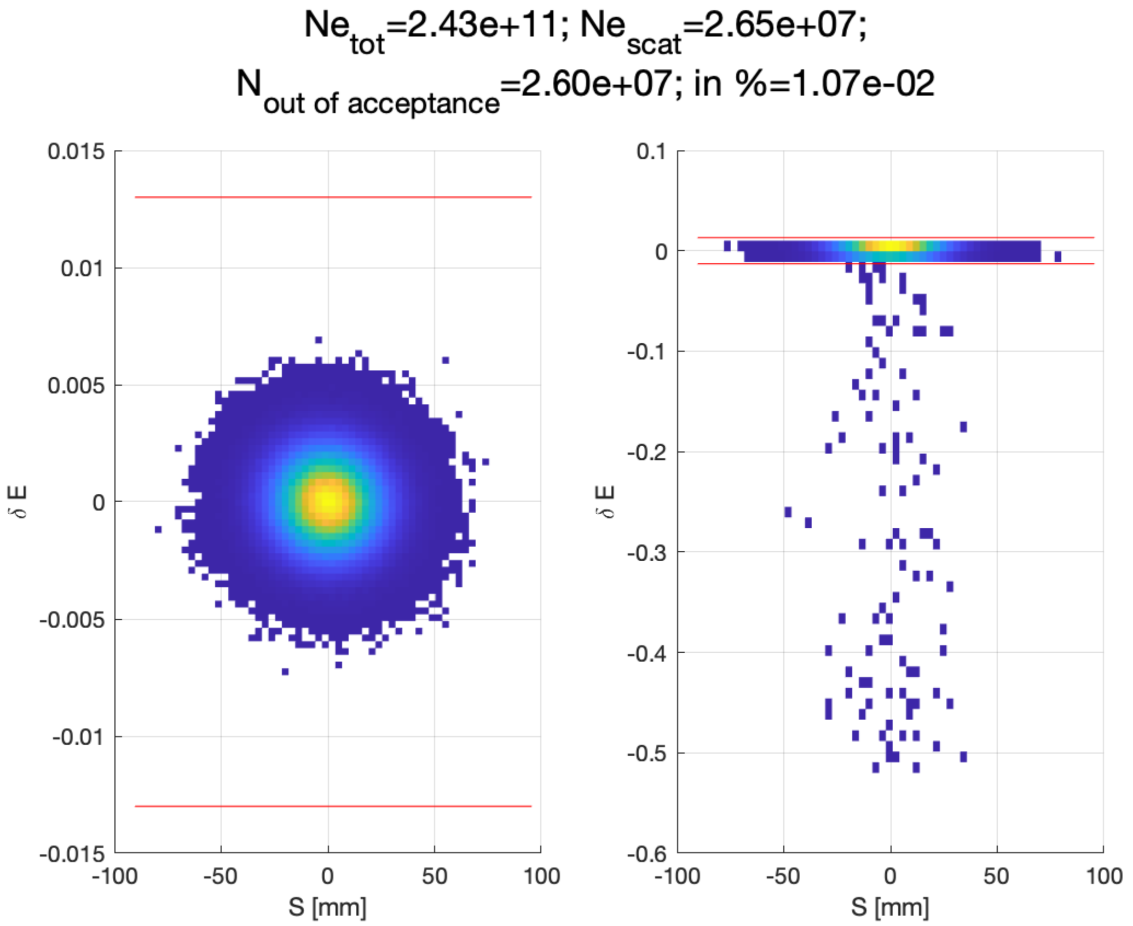
Beam from xsuit z



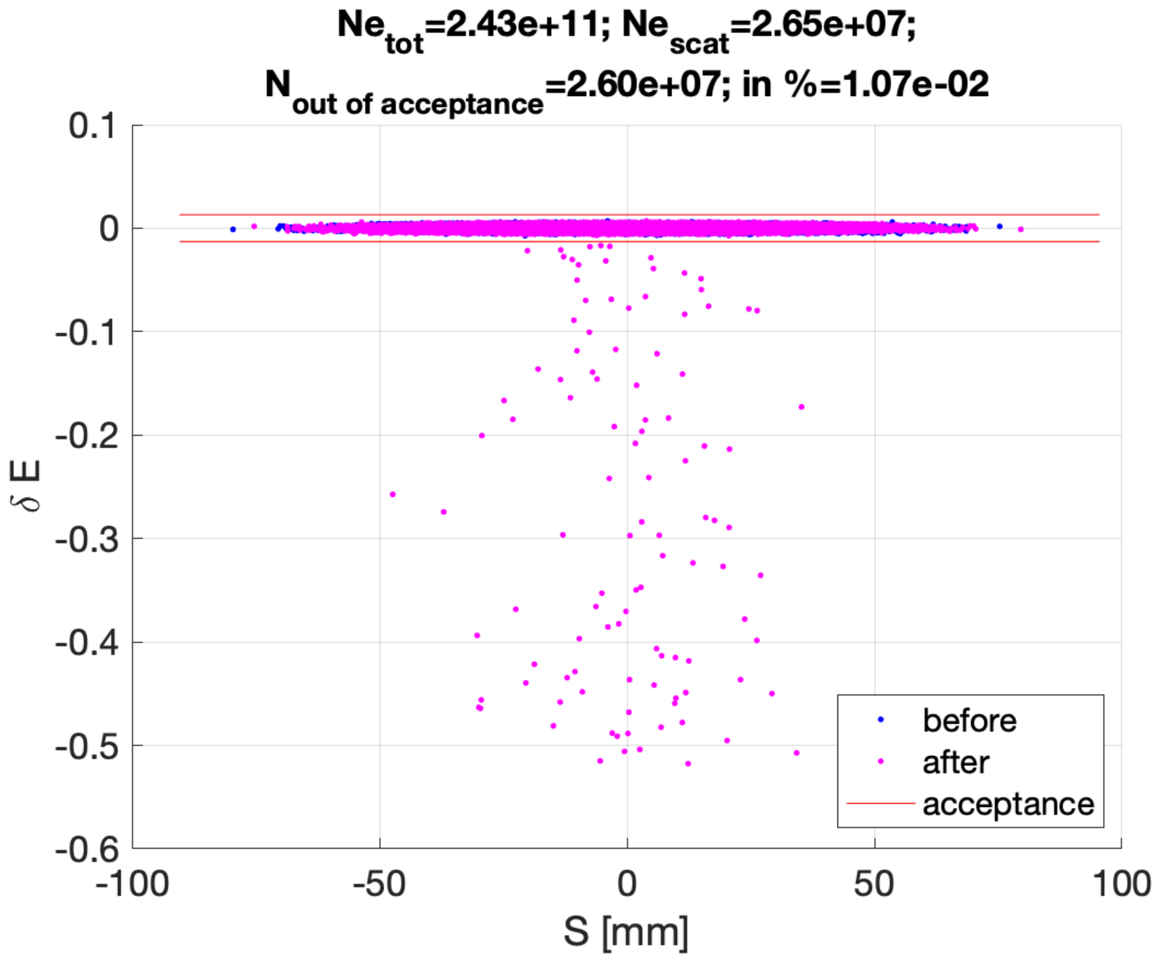


Beam from xsuit z

Energy acceptance 0.013



Ne_{tot}=2.43e+11; Ne_{scat}=2.65e+07;
$N_{out\ of\ acceptance}$=2.60e+07; in %=1.07e-02



Ne_{tot}=2.43e+11; Ne_{scat}=2.65e+07;
$N_{out\ of\ acceptance}$=2.60e+07; in %=1.07e-02

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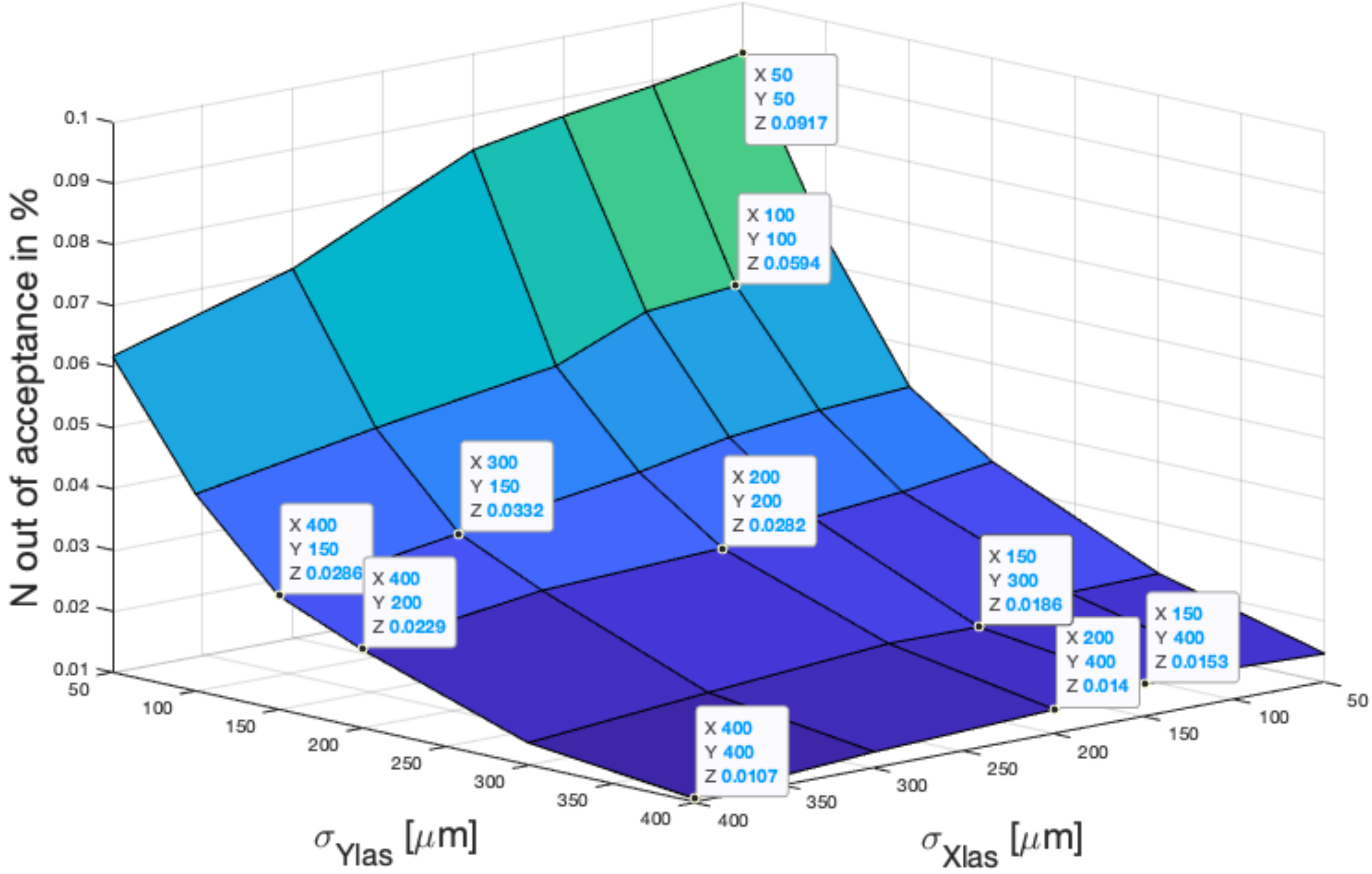
Varying laser focusing at IP



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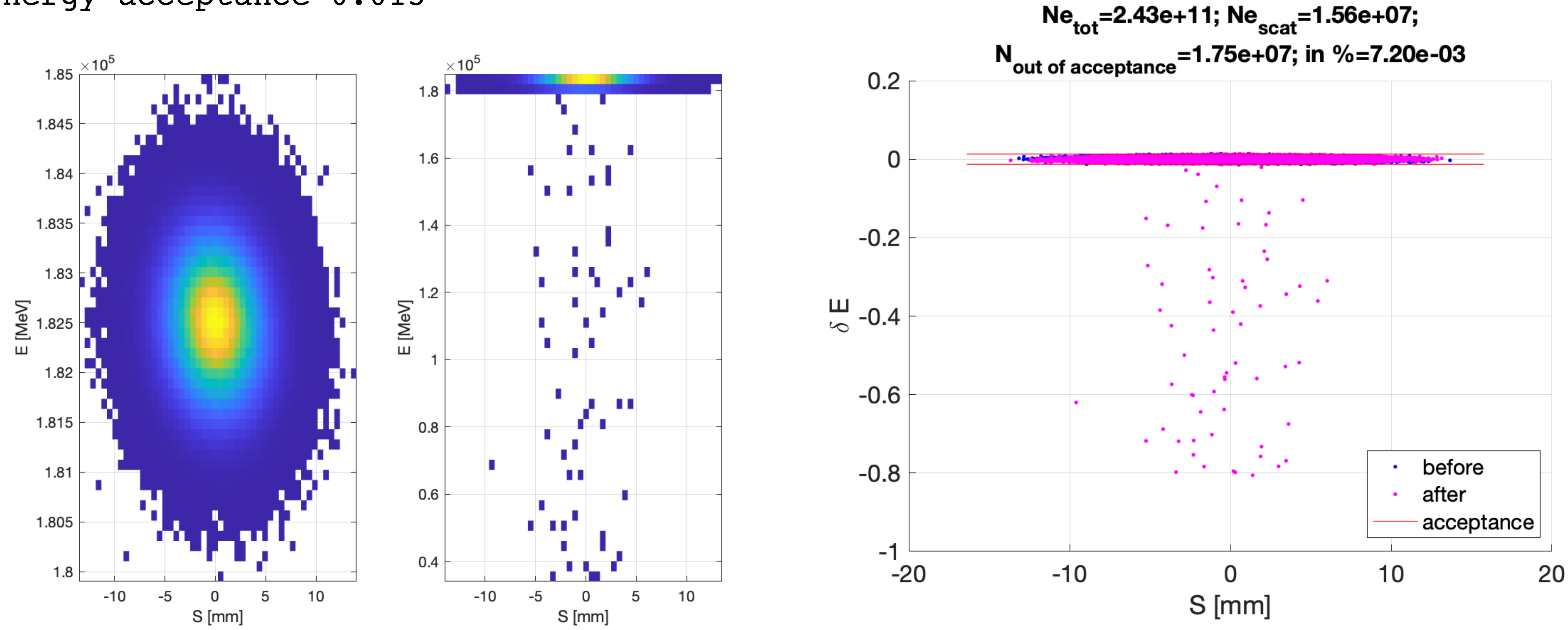
TT BAR

`Energy acceptance 0.013`



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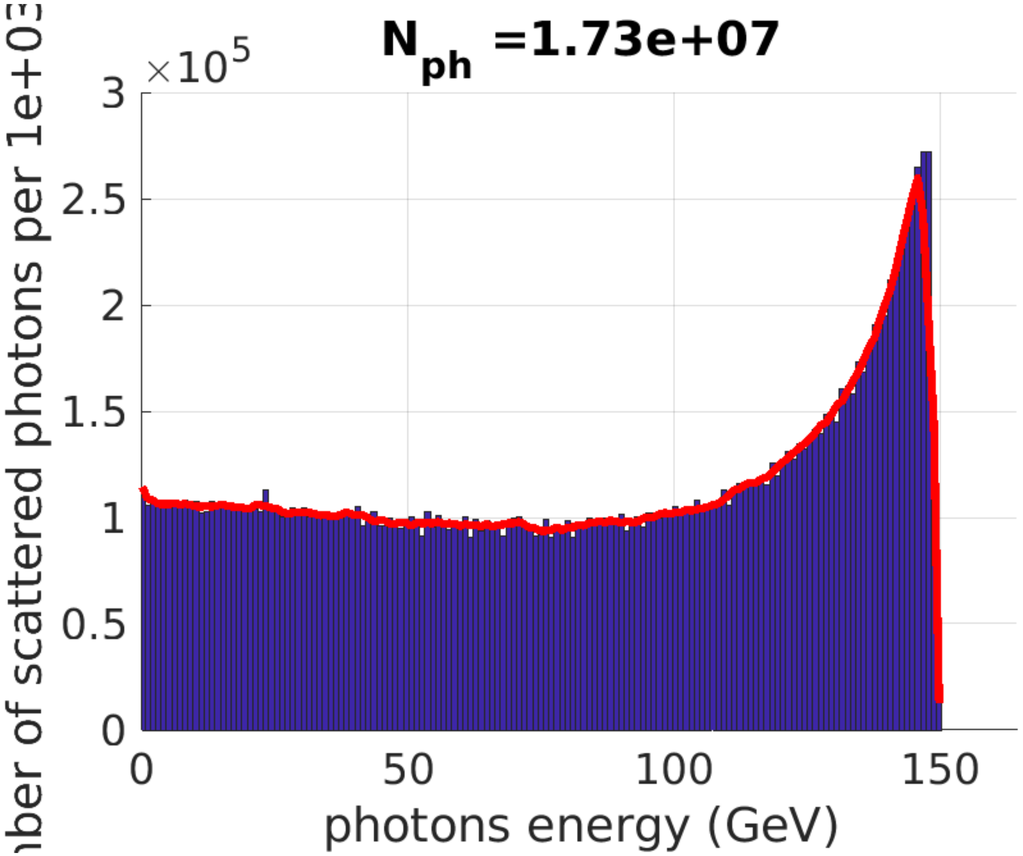
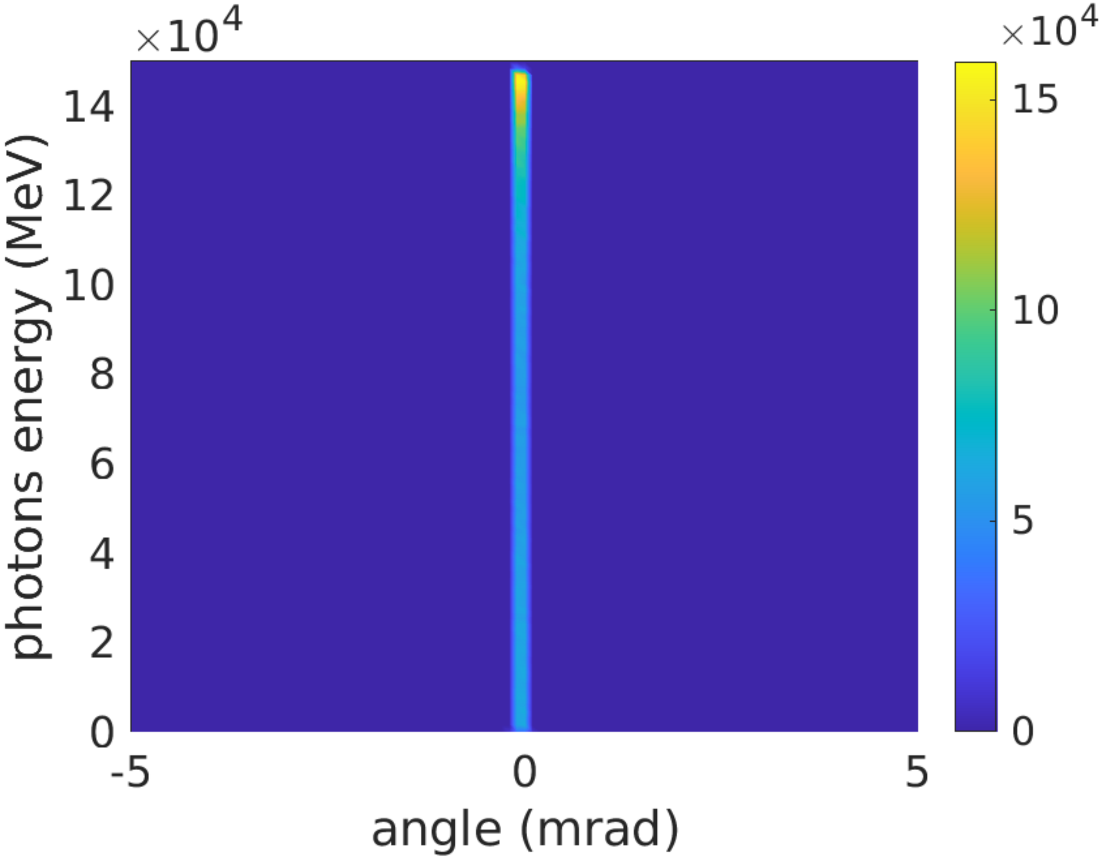
TT BAR





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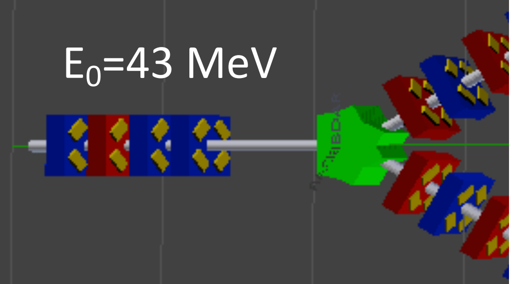
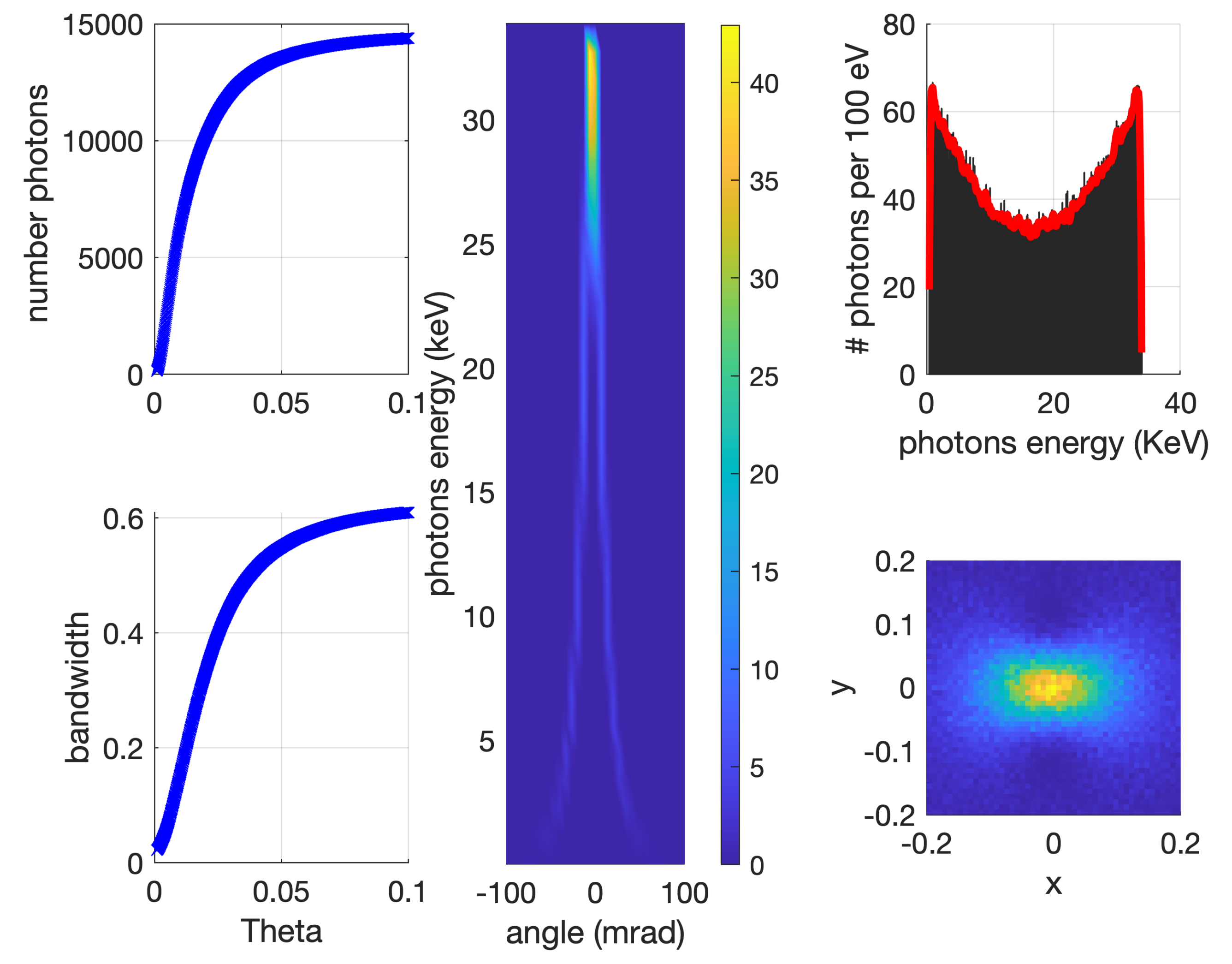
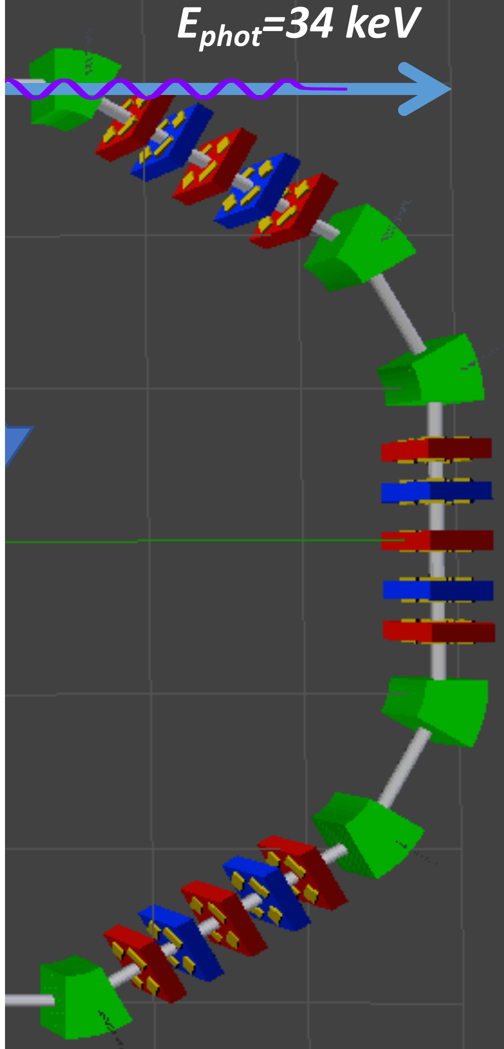
Why we so like Compton back scattering?

The energy angular correlation - tunability

BrIXSinO







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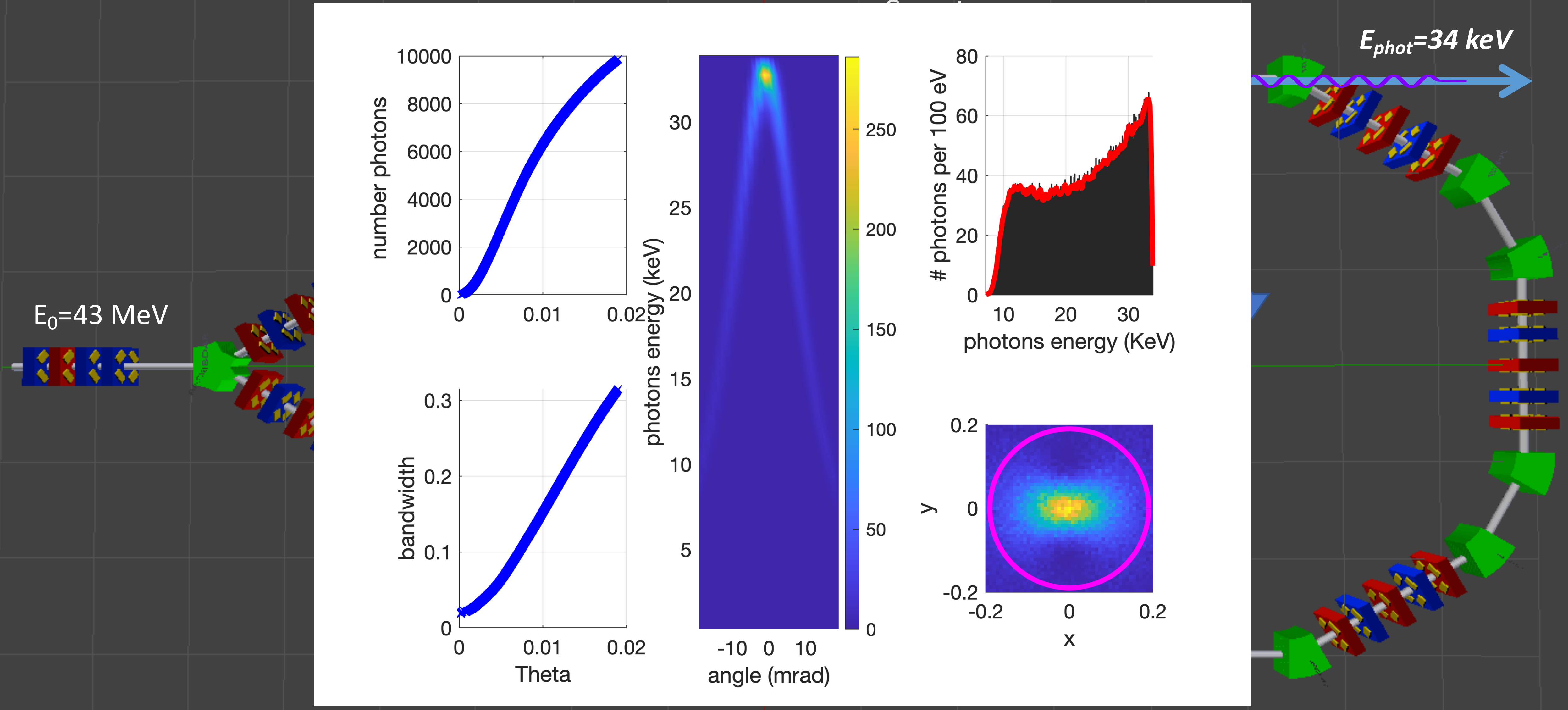

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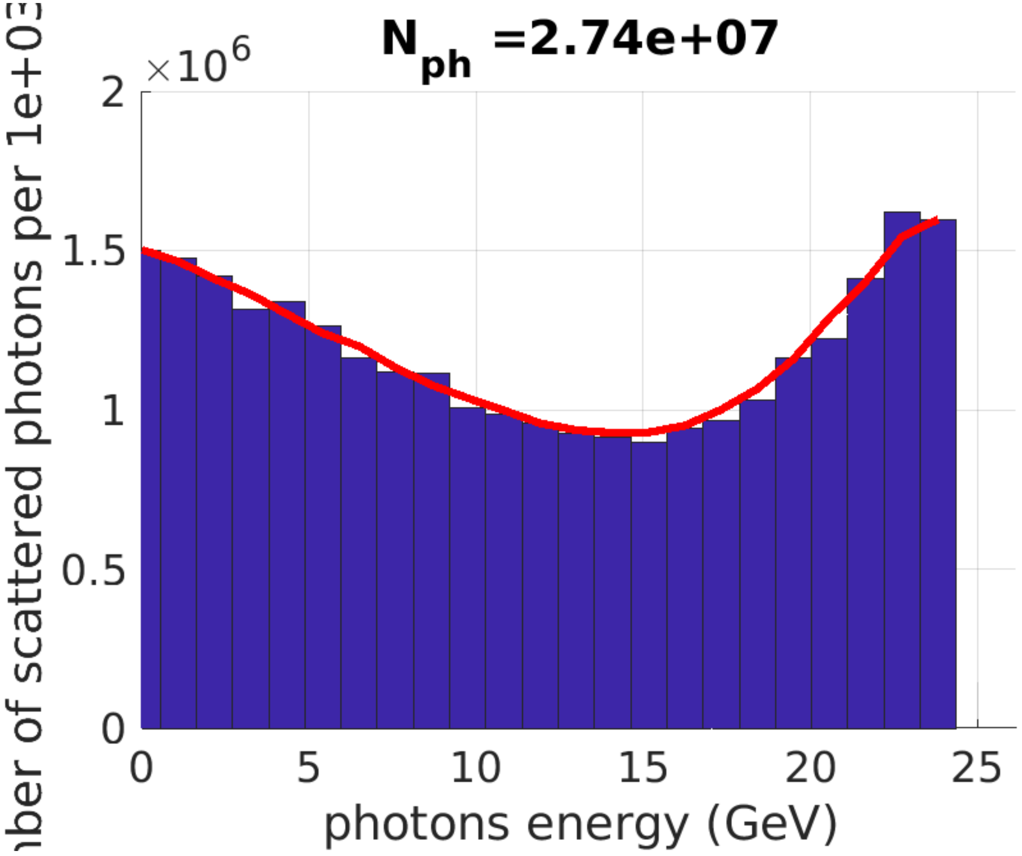
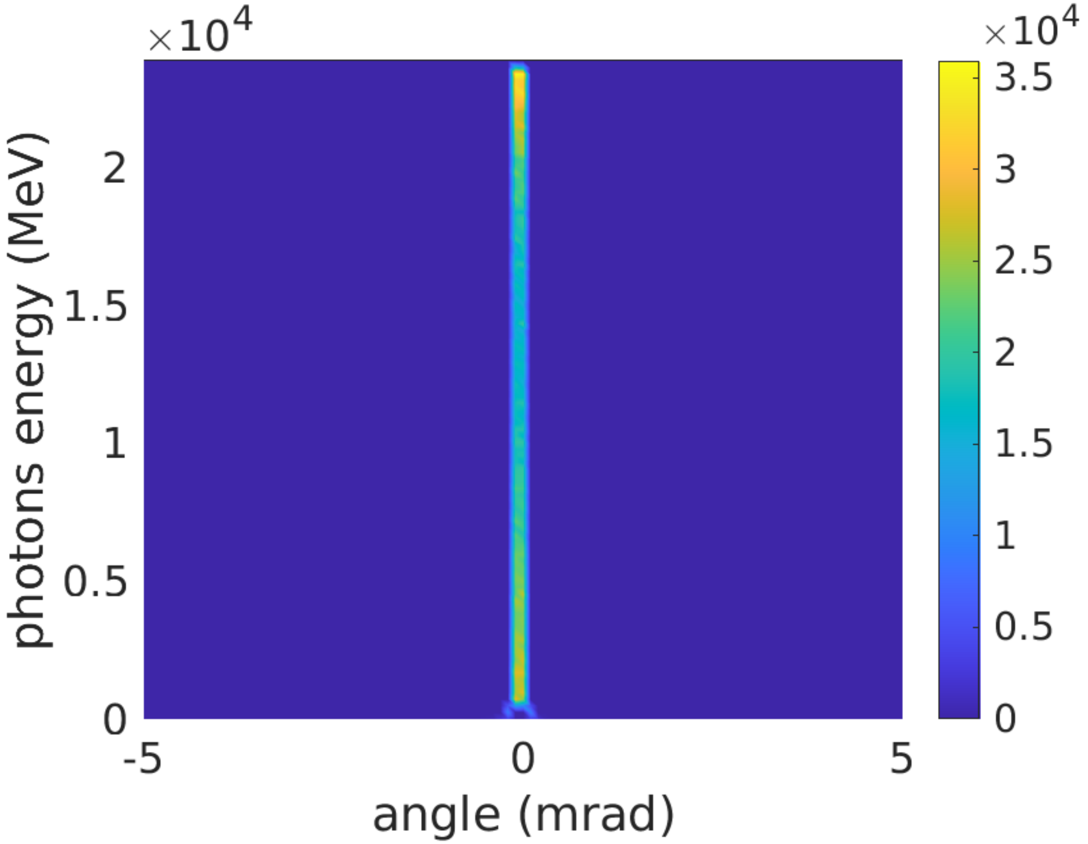
Beam from xsuit z





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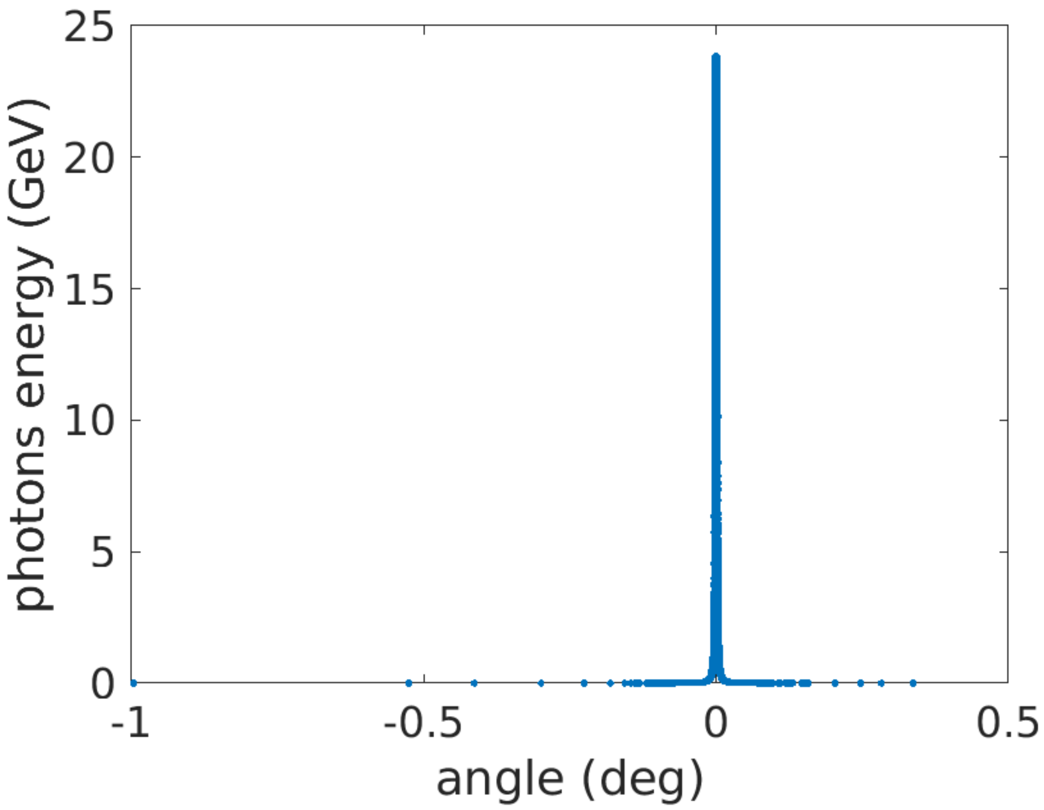
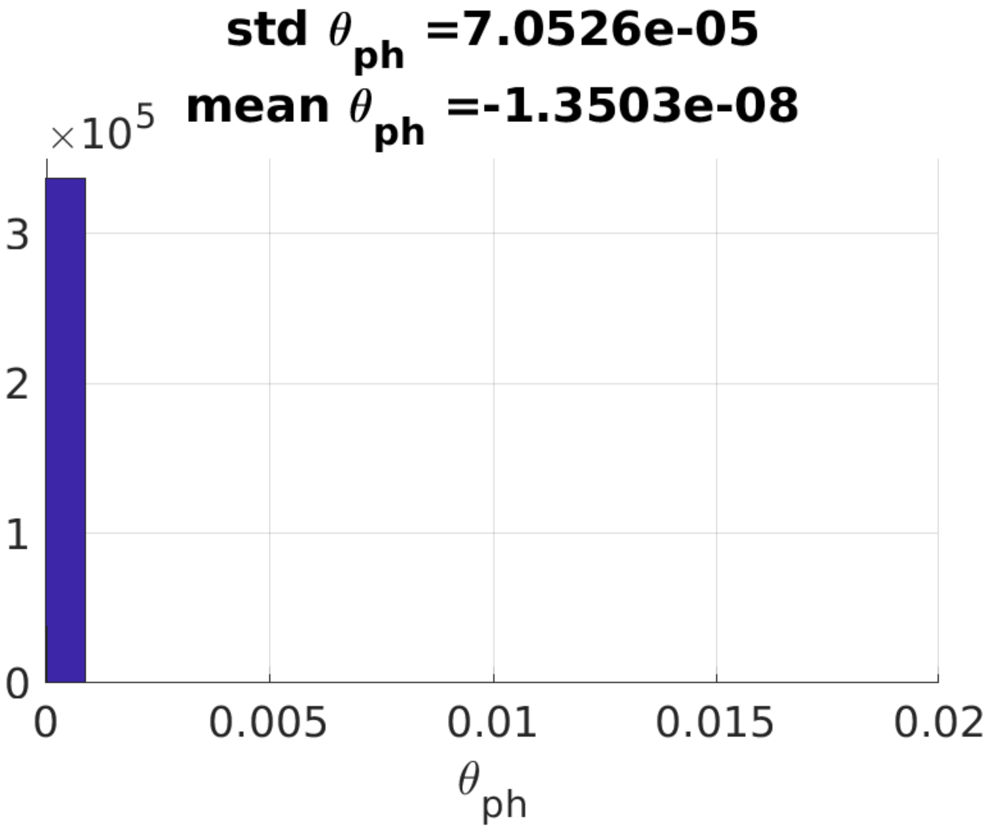
Beam from xsuit z





Weight=80; Number of real photons in one macrophoton

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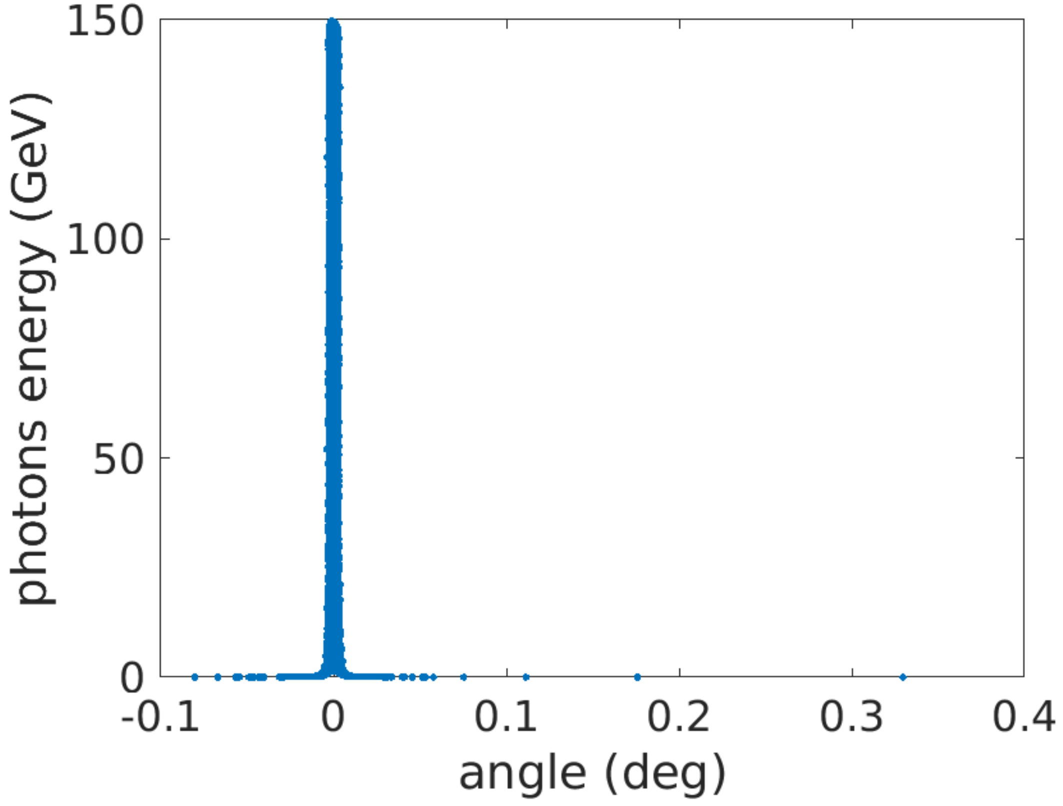
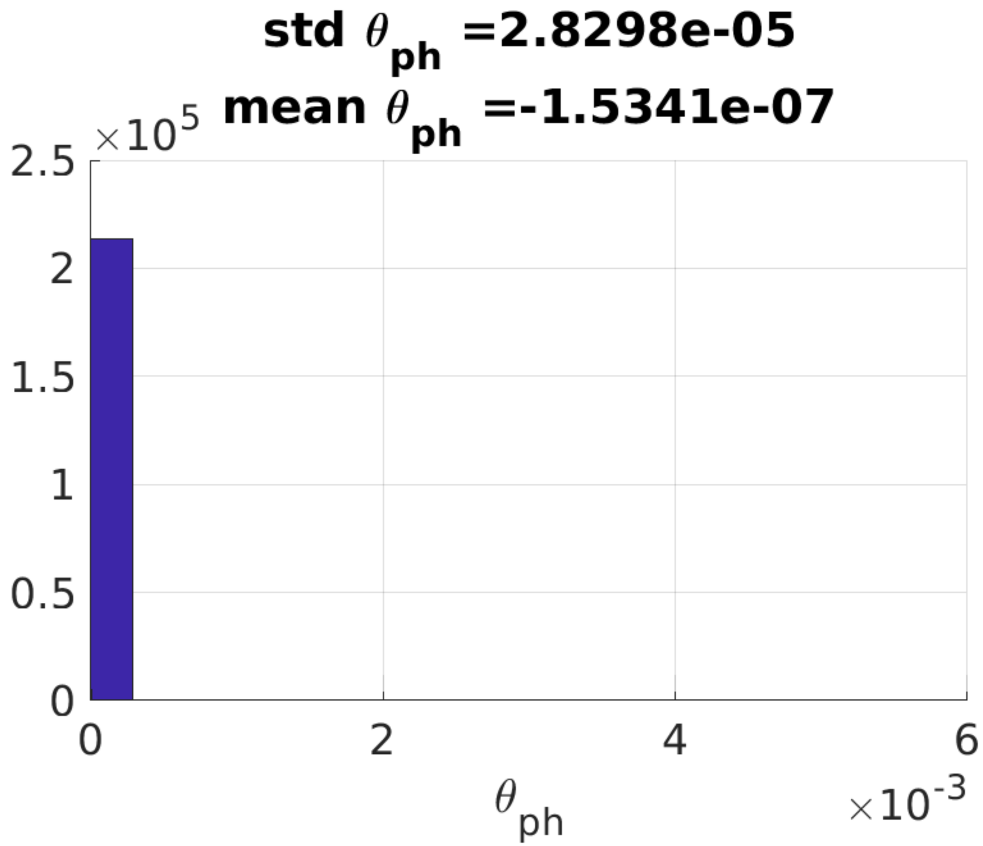
TT BAR





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As conclusion

- With this working parameters we can reduce 1% of bunch charge at 100 turns.
- To increase efficiency of collision we need focused bunches at IP

To-do

- Find better position for IP (more focused beam)
- Make full tracking simulation using beam after collision
- Find application and users for 25 and 150 GeV photon beam 🖖

Thank you

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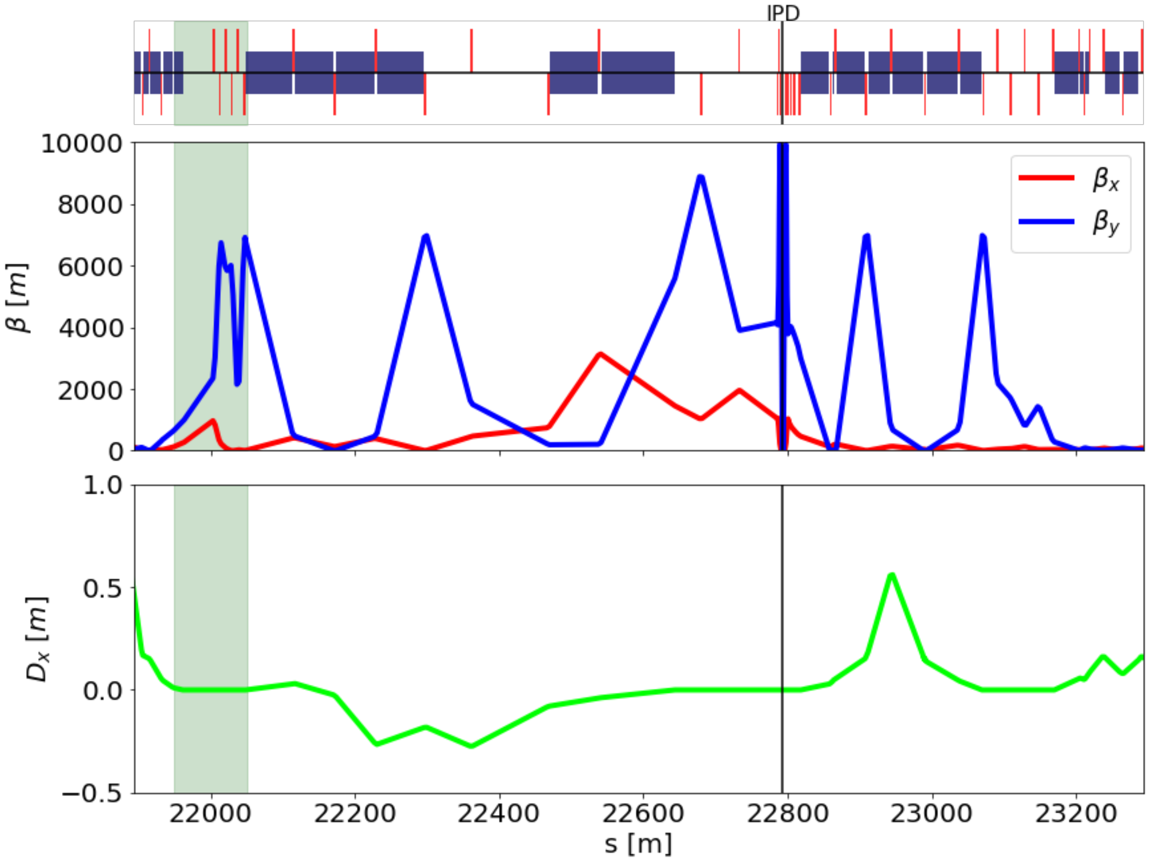
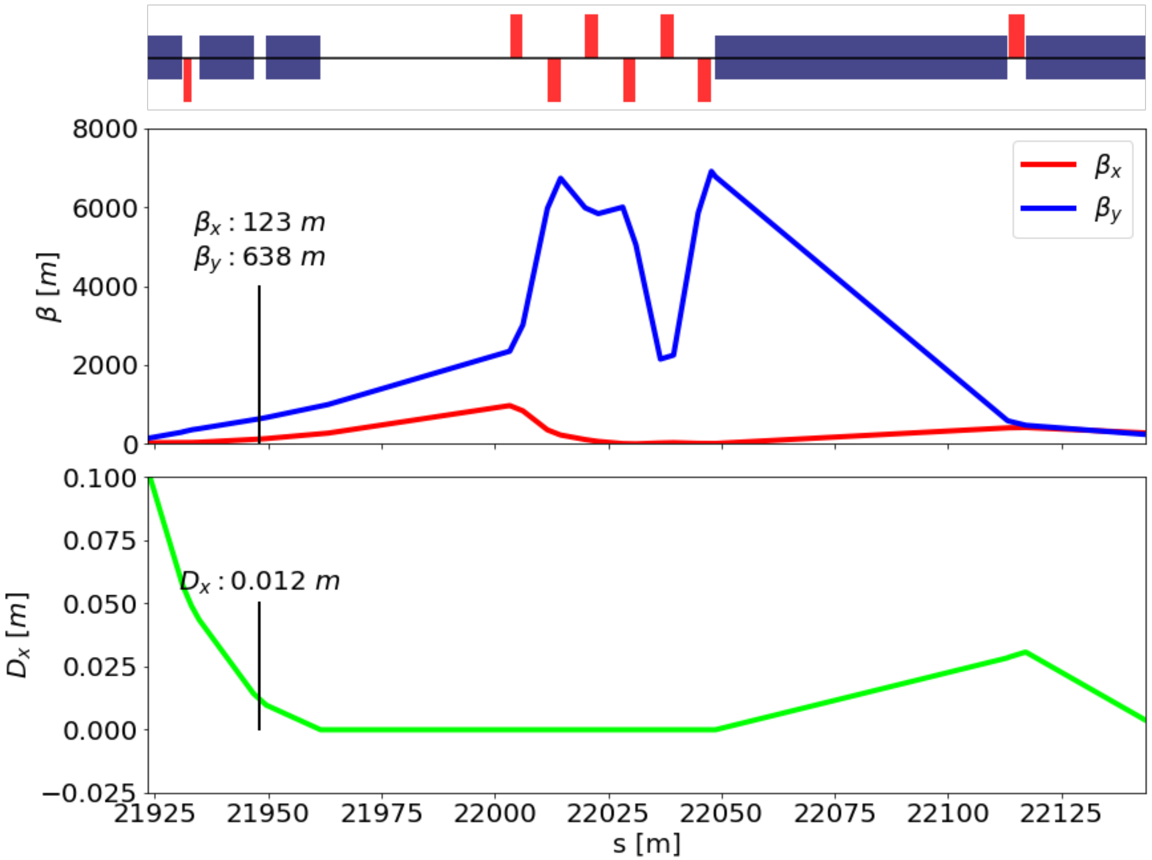
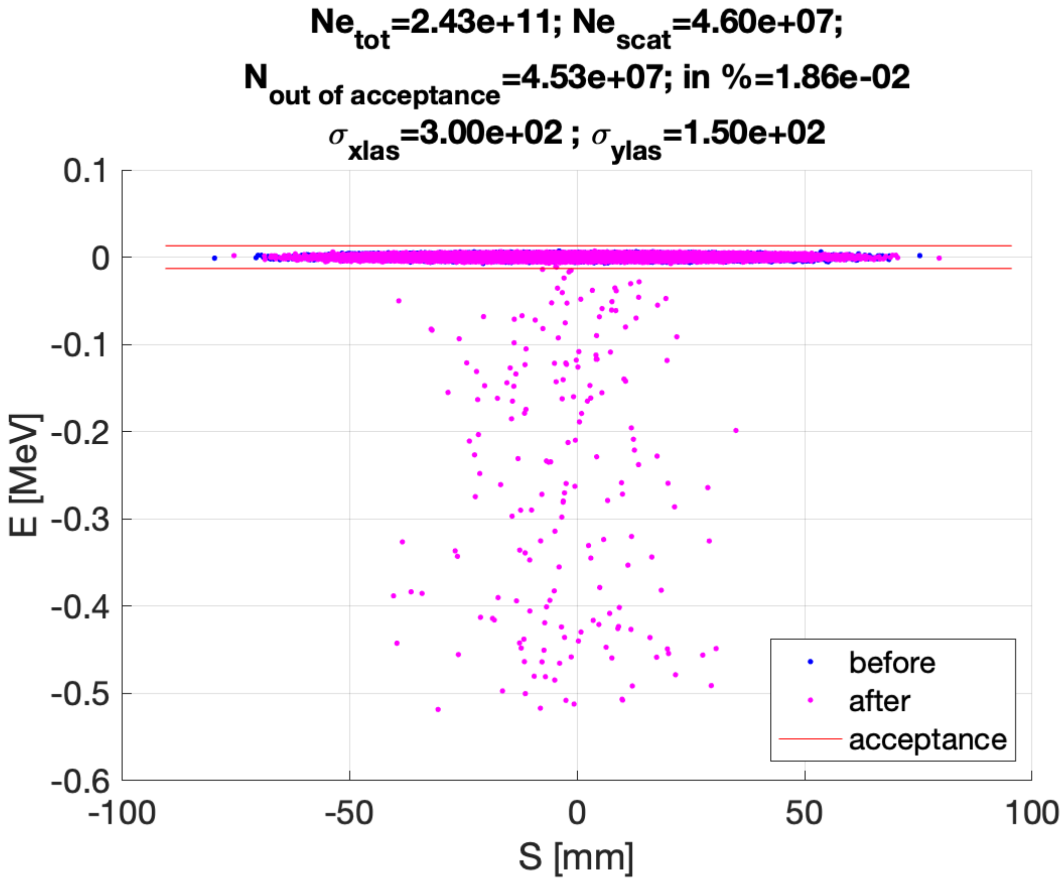

IPD
10000
8000
6000
4000
2000
0
β [m]
β_x
β_y
1.0
0.5
0.0
−0.5
D_x [m]
22000
22200
22400
22600
22800
23000
23200
s [m]


8000
6000
4000
2000
0
β [m]
$\beta_x : 123\ m$
$\beta_y : 638\ m$
β_x
β_y
0.100
0.075
0.050
0.025
0.000
−0.025
D_x [m]
$D_x : 0.012\ m$
21925
21950
21975
22000
22025
22050
22075
22100
22125
s [m]

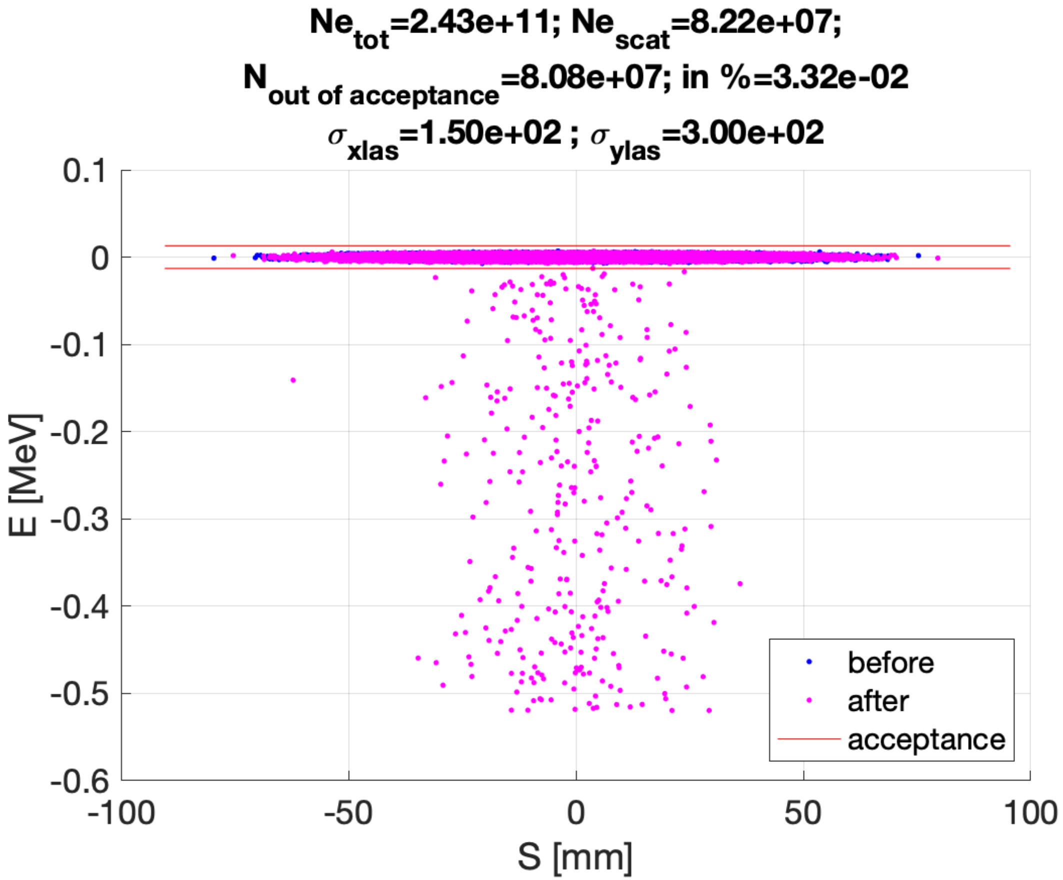
$\sigma_{xlas} = 300\ \mu m$

$\sigma_{ylas} = 150\ \mu m$



$\sigma_{xlas} = 150\ \mu m$

$\sigma_{ylas} = 300\ \mu m$



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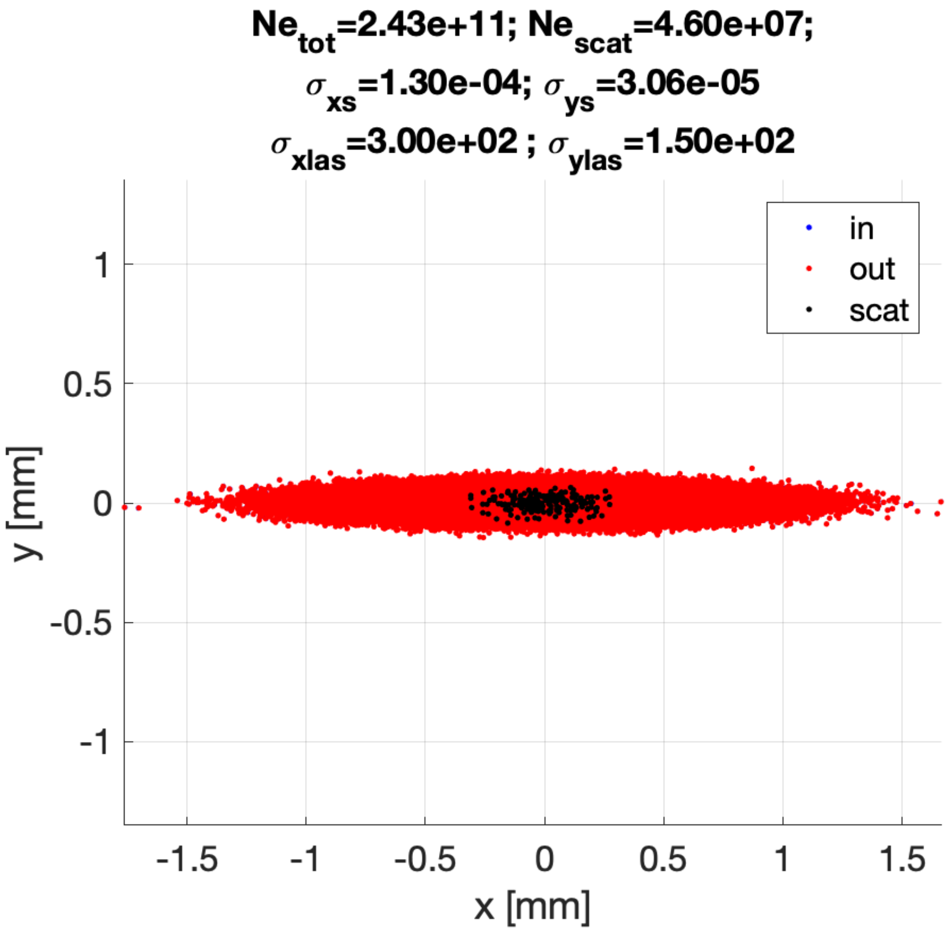
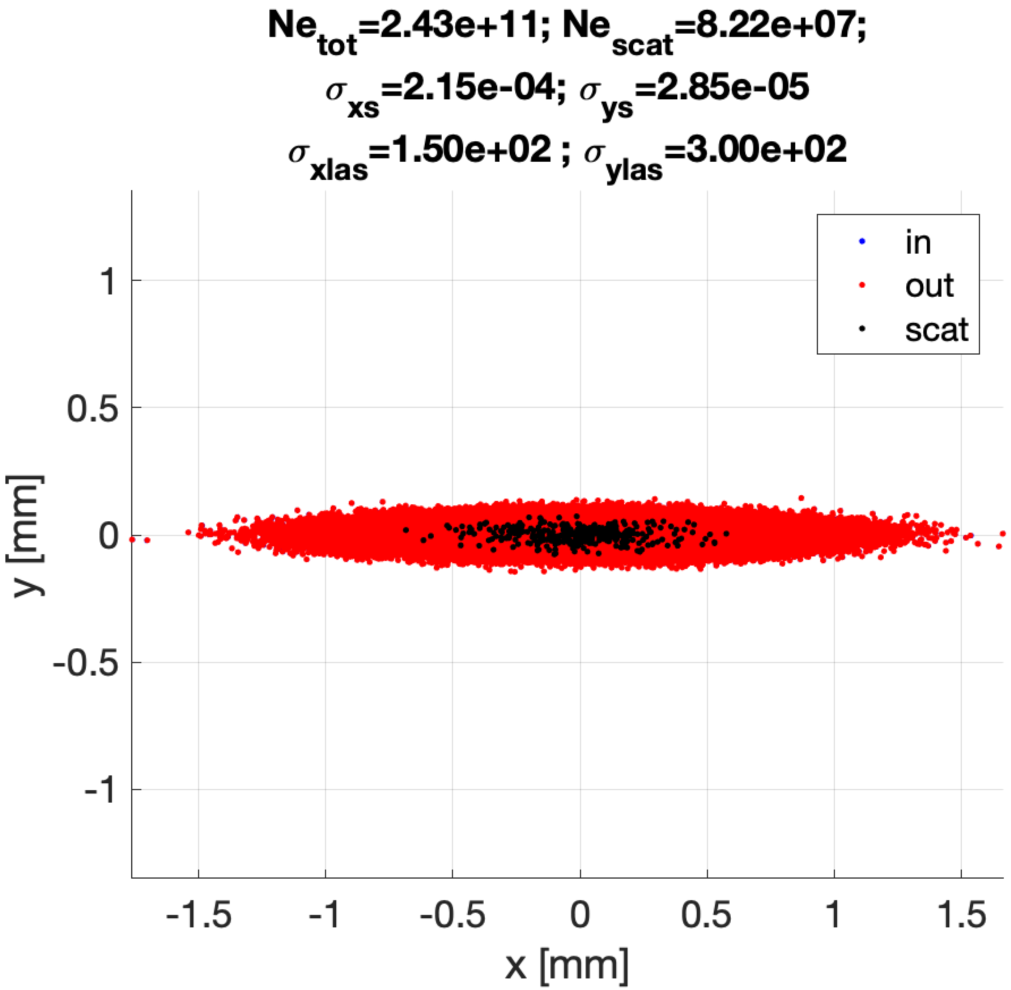
$\sigma_{xlas} = 300\ \mu m$

$\sigma_{ylas} = 150\ \mu m$

$\sigma_{xlas} = 150\ \mu m$

$\sigma_{ylas} = 300\ \mu m$





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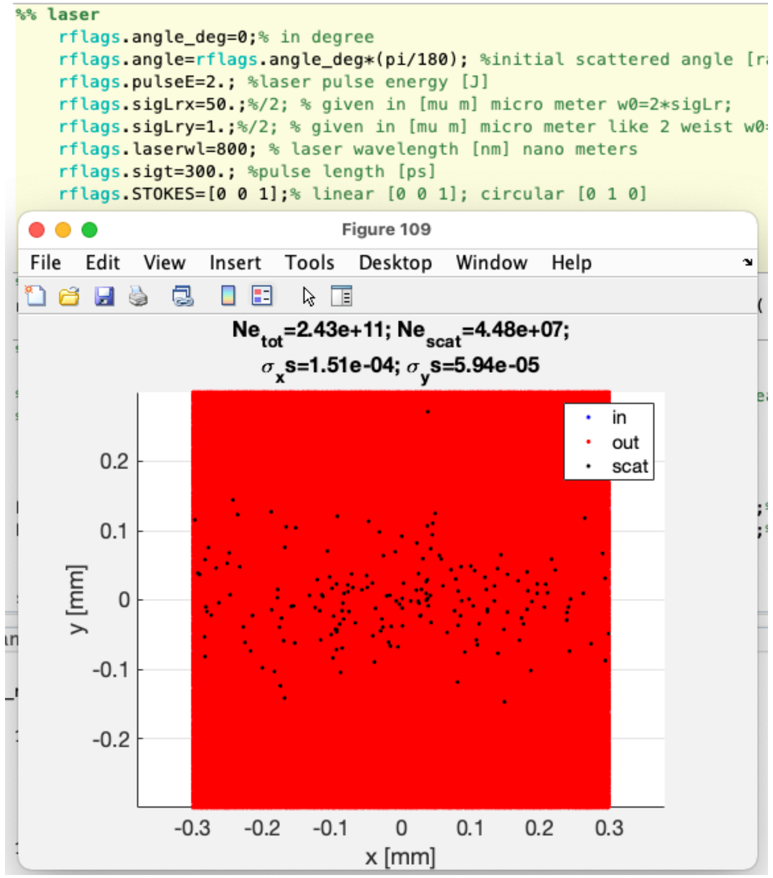
Check X Y plane for laser

Test simulation done with uniform distribution in transvers plane and almost no emittance

$\sigma_{xlas} = 50\ \mu m$

$\sigma_{ylas} = 1\ \mu m$

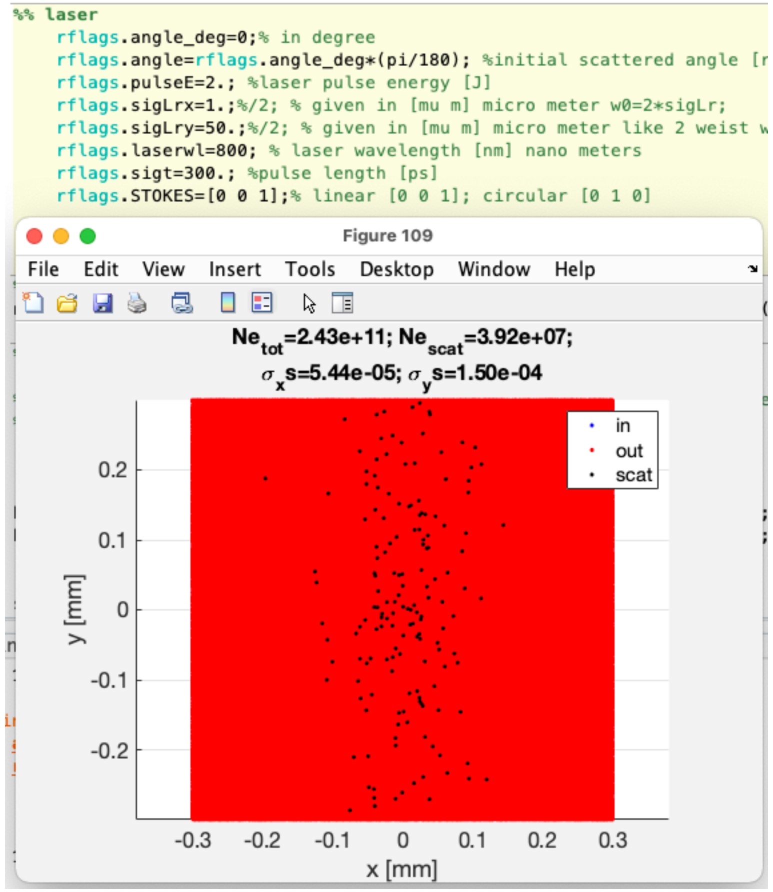


```
%% laser
    rflags.angle_deg=0;% in degree
    rflags.angle=rflags.angle_deg*(pi/180); %initial scattered angle [r
    rflags.pulseE=2.; %laser pulse energy [J]
    rflags.sigLrx=50.;%/2; % given in [mu m] micro meter w0=2*sigLr;
    rflags.sigLry=1.;%/2; % given in [mu m] micro meter like 2 weist w0
    rflags.laserwl=800; % laser wavelength [nm] nano meters
    rflags.sigt=300.; %pulse length [ps]
    rflags.STOKES=[0 0 1];% linear [0 0 1]; circular [0 1 0]
```

Ne_{tot}=2.43e+11; Ne_{scat}=4.48e+07;
σ_xs=1.51e-04; σ_ys=5.94e-05

$\sigma_{xlas} = 1\ \mu m$

$\sigma_{ylas} = 50\ \mu m$



```
%% laser
    rflags.angle_deg=0;% in degree
    rflags.angle=rflags.angle_deg*(pi/180); %initial scattered angle [r
    rflags.pulseE=2.; %laser pulse energy [J]
    rflags.sigLrx=1.;%/2; % given in [mu m] micro meter w0=2*sigLr;
    rflags.sigLry=50.;%/2; % given in [mu m] micro meter like 2 weist w
    rflags.laserwl=800; % laser wavelength [nm] nano meters
    rflags.sigt=300.; %pulse length [ps]
    rflags.STOKES=[0 0 1];% linear [0 0 1]; circular [0 1 0]
```

Ne_{tot}=2.43e+11; Ne_{scat}=3.92e+07;
σ_xs=5.44e-05; σ_ys=1.50e-04

Difference with realistic beam can be due to big unsymmetry not just in size but also in emittance

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