Investigation of the Thomson scattering influence on electron beam parameters in an energy-recovering linear Accelerator on the example of MESA

Christoph Lorey (KPH, Mainz)
Atoosa Meseck (KPH, Mainz)
Paul Ignatius Volz (HZB, Berlin)

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

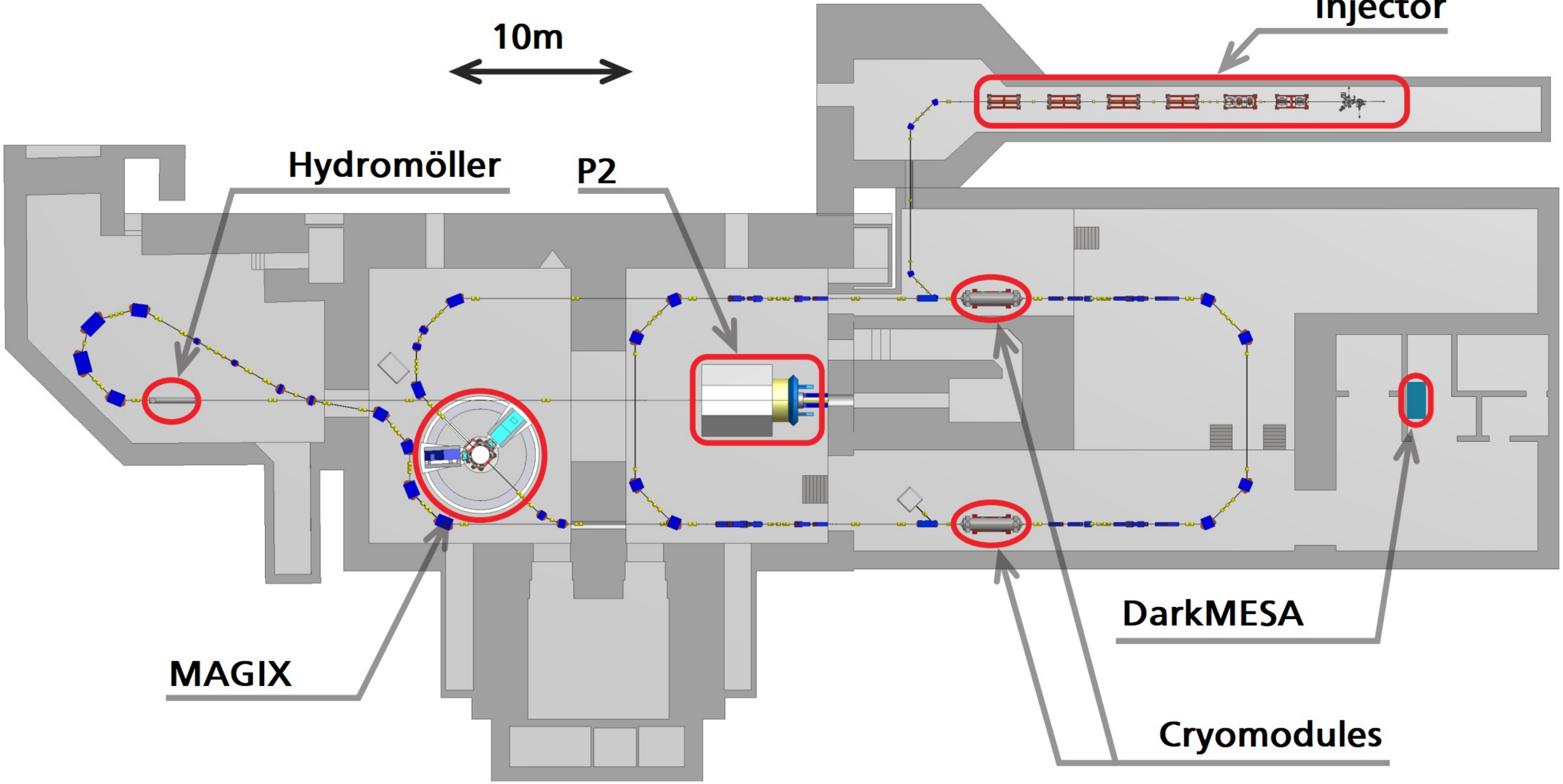
ACCELENCE

Gefördert durch die DFG im Rahmen des GRK 2128

Mainz Energy-Recovering Superconducting Accelerator (MESA) Layout

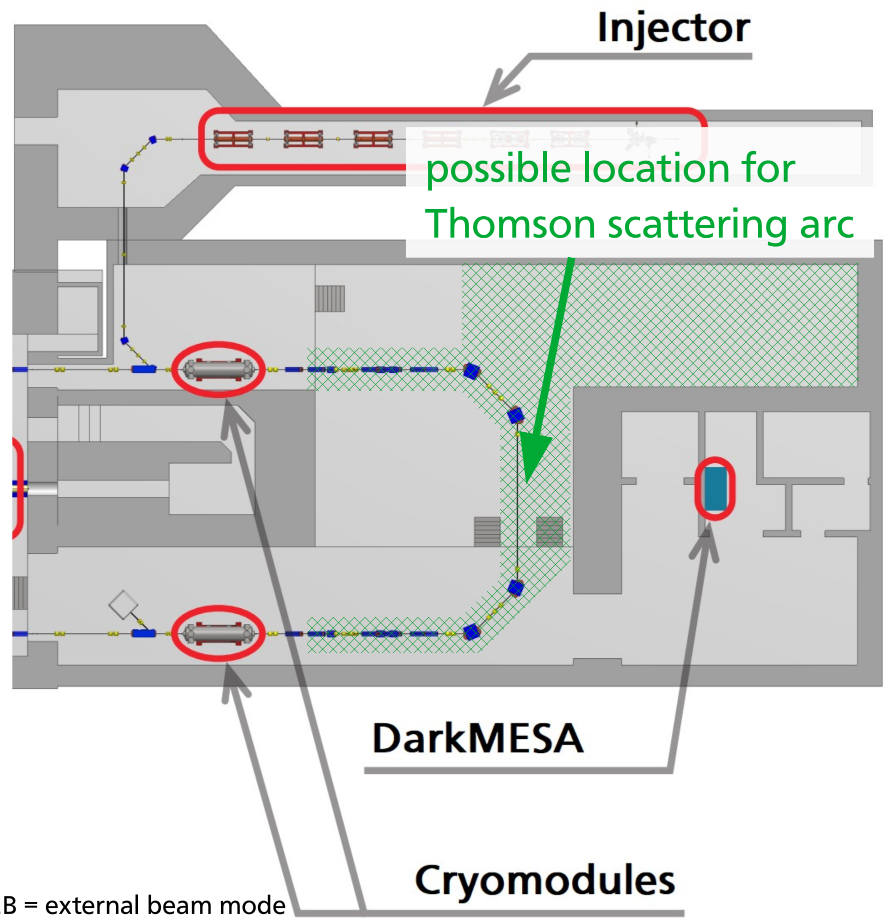
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Graphic is a modified version of Fig.1.2 in D.Simon's „Gesamtkonzept für den MESA-Teilchenbeschleuniger unter besonderer Berücksichtigung von Strahloptik und Kryotechnik" PhD Thesis



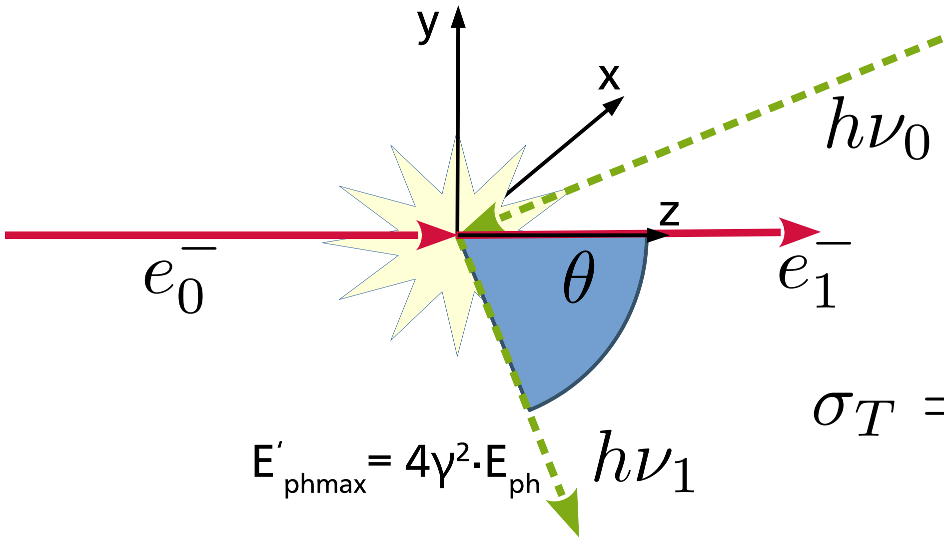
Mainz Energy-Recovering Superconducting Accelerator (MESA)

Beam energy ER/EB	[MeV]	105 / 155 / 130MeV potential Thomson scattering mode
Injection Energy	[MeV]	5
Operating mode		CW
Source type		DC 100 keV, pol. (DC 200 keV, pol.)
Bunch charge ER/EB	[pC]	0.77 / 0.12 (7.7 / 0.12)
Norm. emittance ER/EB	[µm]	< 1 / 0.15 (< 2 / 0.15)
Beam polarisation EB		> 0.85
Accelerating passes ER/EB		2/3
Beam power at exp. ER/EB	[kW]	100 / 23 (1000 / 23)
RF-frequency	[MHz]	1300
RF-power installed	[kW]	300
Main linac energy gain/turn	[MeV]	50
Main linac gradient	[MV/m]	13 (16)



*EB = external beam mode
ER = energy recovery mode

Brief overview of Thomson scattering parameters



θ: observation angle of scattered photon in lab reference system

Thomson cross-section is very low:

$$\sigma_T = \frac{8\pi}{3} r_e^2 \simeq 6.6525 \cdot 10^{-29} m^2$$

invariant mass E_{cm} is preserved: [1] $\mathrm{E}_{cm} = m_e c^2 \sqrt{1 + \Delta}$

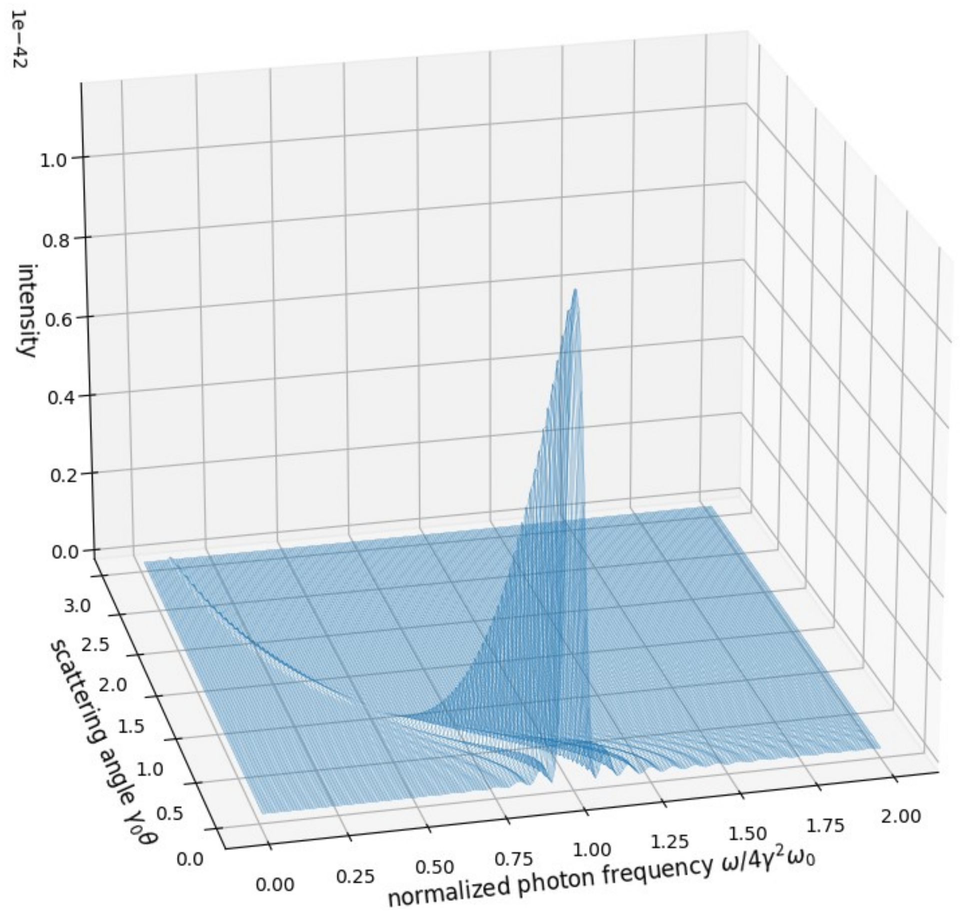
3D Recoil factor : $\Delta \equiv \frac{2h\nu\gamma}{m_e c^2} + \frac{2\hbar c^2}{m_e^2 c^4} \left(k_x P_x + k_y P_y + k_z P_z \right)$

electron & photon 3D-momenta

[1] Curatolo, C.. “High brilliance photon pulses interacting with relativistic electron and proton beams.” (2016).

ThoBaSCo calculation of normalized scattered photon intensity for 130MeV MESA & 1132nm Laser

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



E_e = 130 *MeV*

Q_{bunch} = 0.77 *pC*

σ_e = $1.205 \cdot 10^{-4}$ *m*

mn_e = 2000

linear polarisation

λ = 1132 *nm*

E_{ph} ≈ 1.0953 *eV*

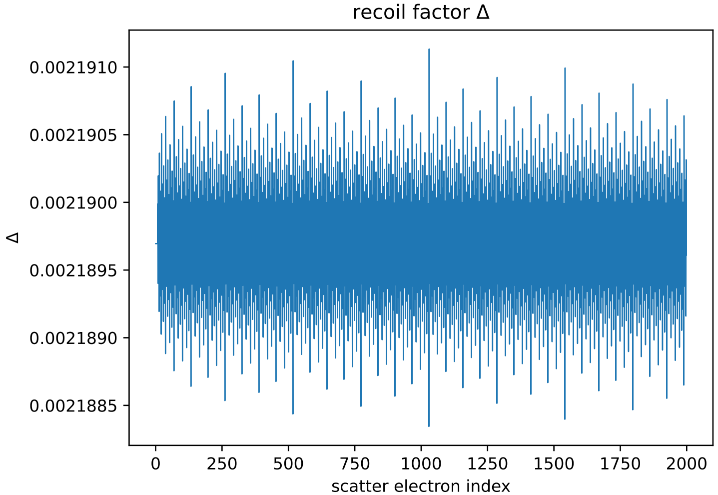
I_0 ≈ $5.7170 \cdot 10^{11}$ *W/cm²*

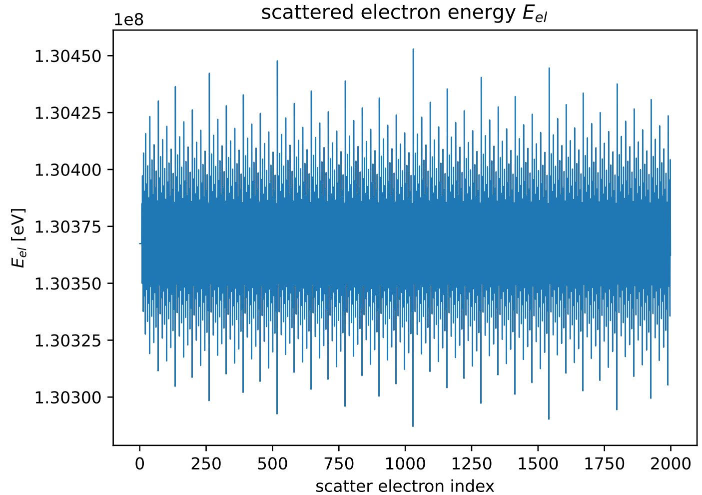
a_0 ≈ $7.2740 \cdot 10^{-4}$

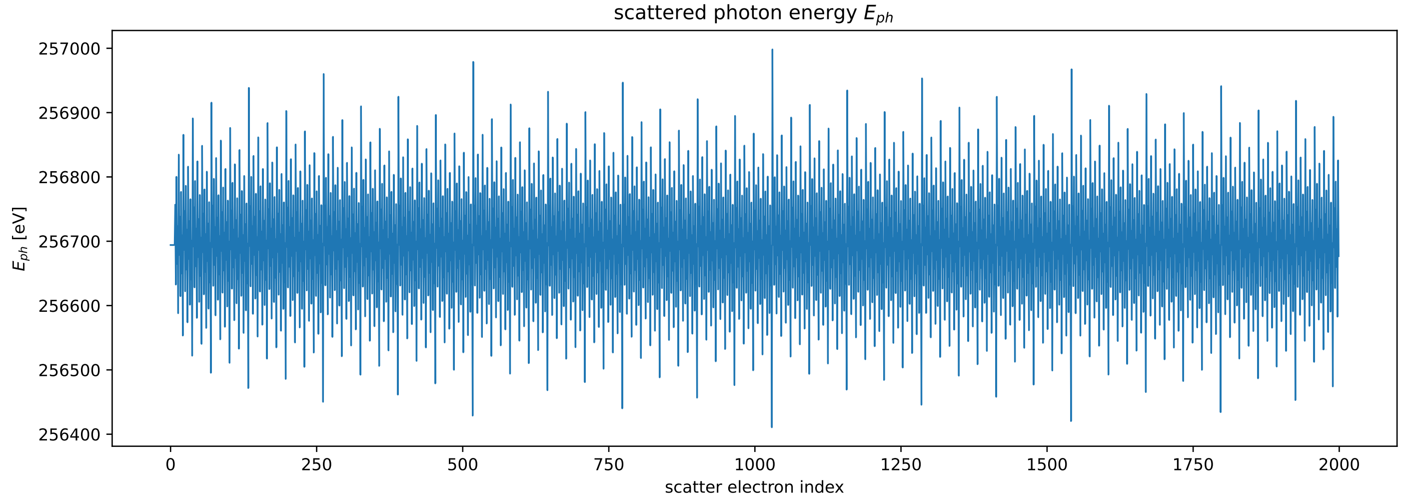
$4\gamma^2 E_{ph}$ ≈ 0.2858 *MeV*

Python calculations for Thomson scattering of 130MeV MESA electron bunch & 1132nm Laser at observation angle θ = 1/(3γ)

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

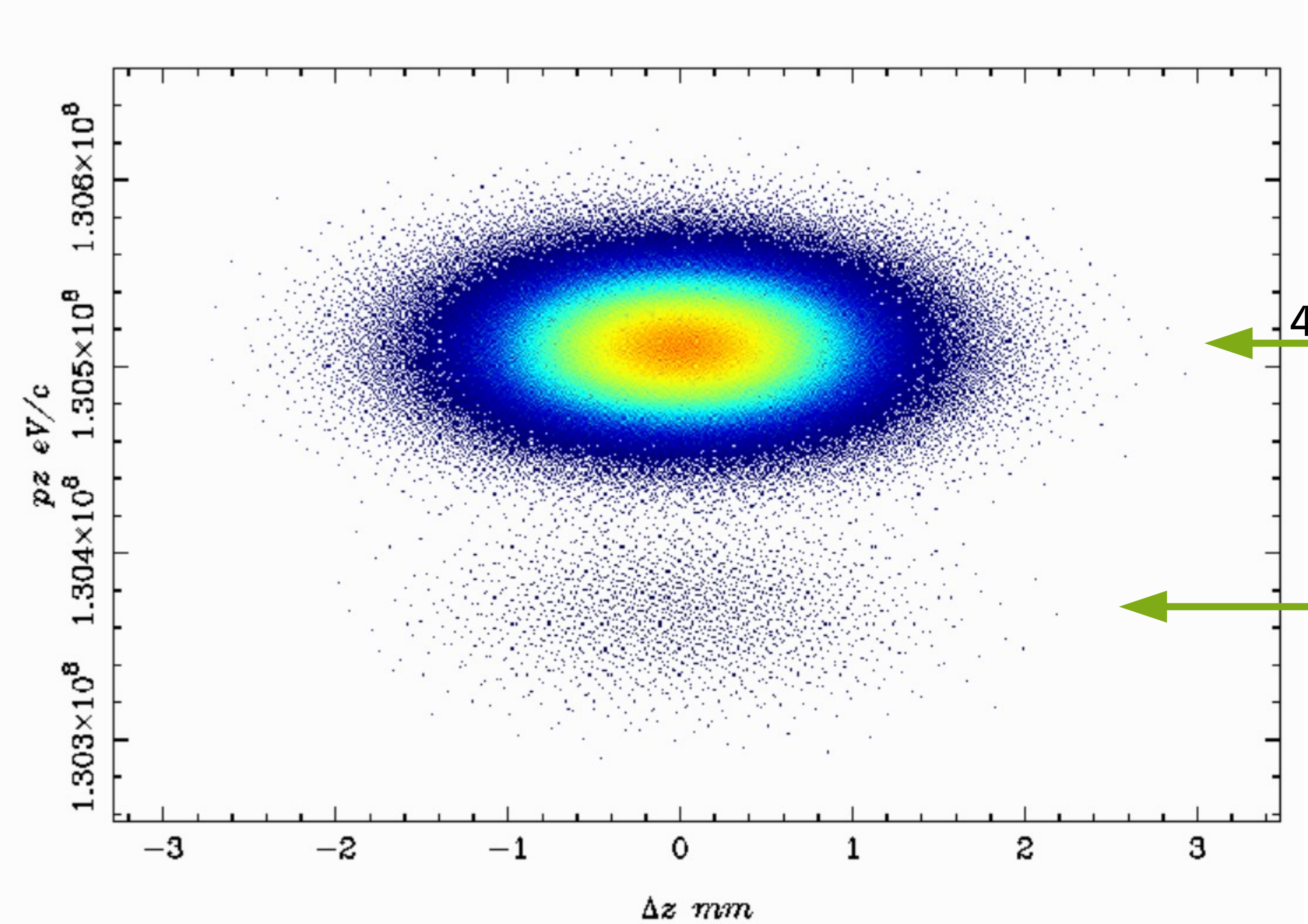






Longitudinal phase space of MESA 130MeV 0.77pC electron bunch after 1132nm Thomson scattering

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



$4.8045 \cdot 10^6$ electrons

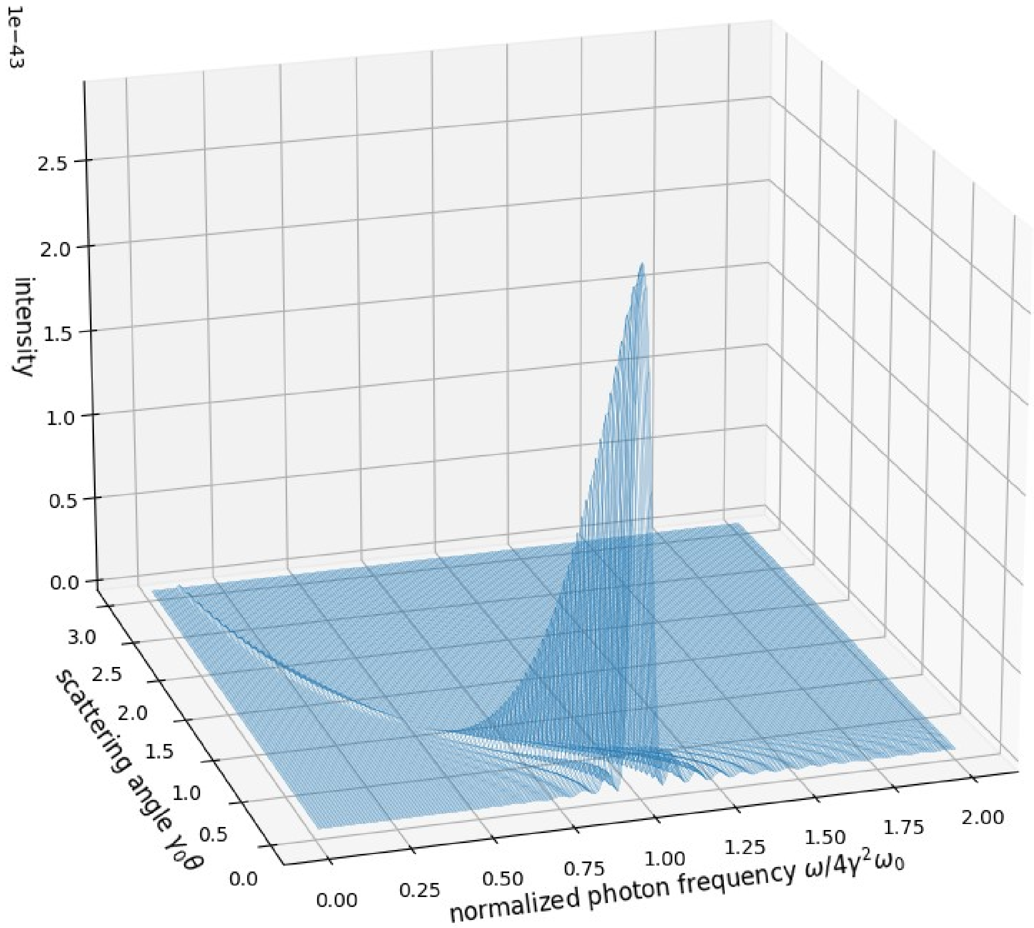
$\bar{E}_e \approx 130.511$ MeV

2k electrons

$\bar{E}_e \approx 130.368$ MeV

ThoBaSCo calculation of normalized scattered photon intensity for 130MeV MESA & 566nm Laser

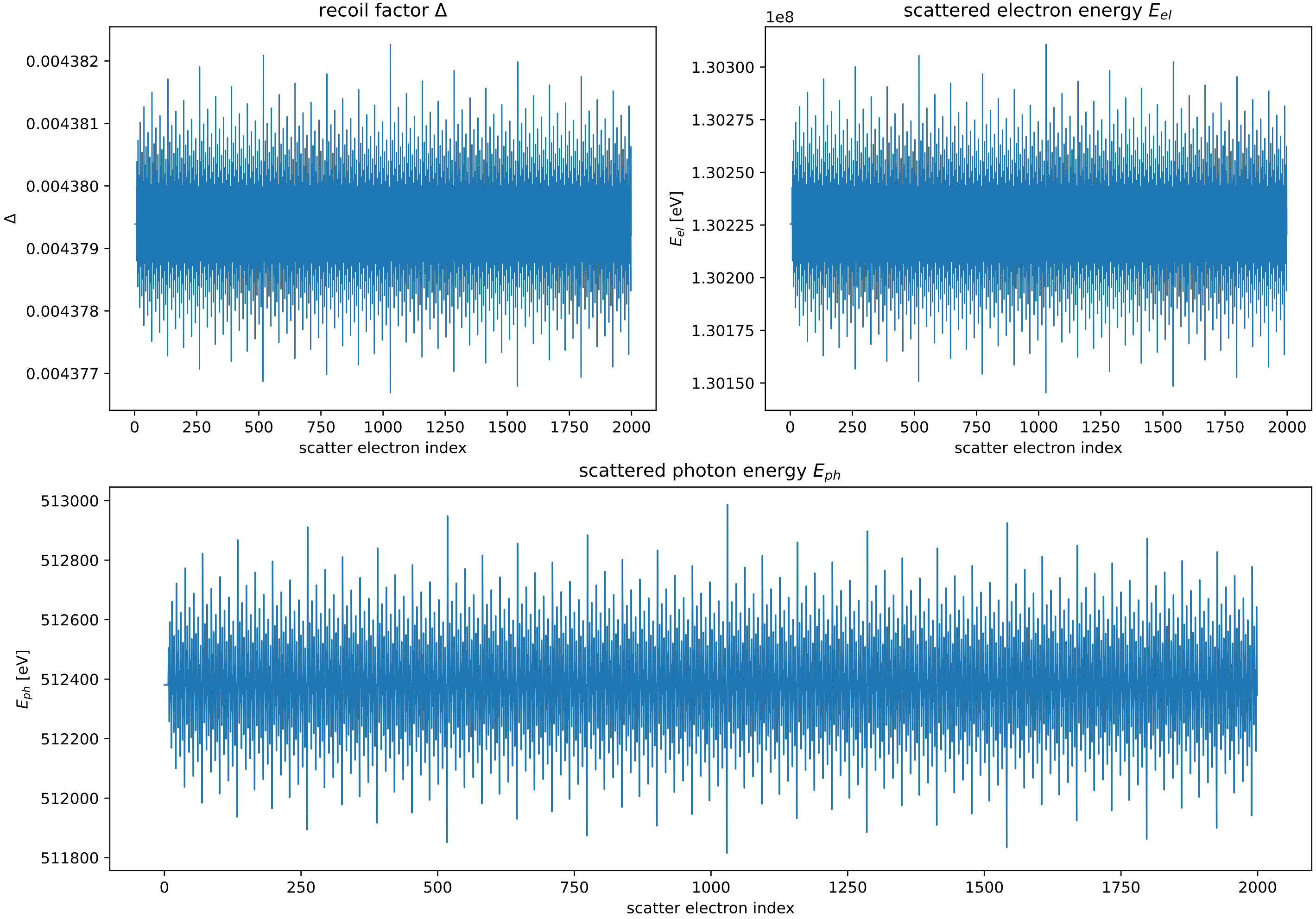
JOHANNES GUTENBERG UNIVERSITÄT MAINZ



E_e	$= 130\ MeV$
Q_{bunch}	$= 0.77\ pC$
σ_e	$= 1.205 \cdot 10^{-4}\ m$
mn_e	$= 2000$
linear	polarisation
λ	$= 566\ nm$
E_{ph}	$\approx 2.1905\ eV$
I_0	$\approx 5.7170 \cdot 10^{11}\ W/cm^2$
a_0	$\approx 3.6370 \cdot 10^{-4}$
$4\gamma^2 E_{ph}$	$\approx 0.5716\ MeV$

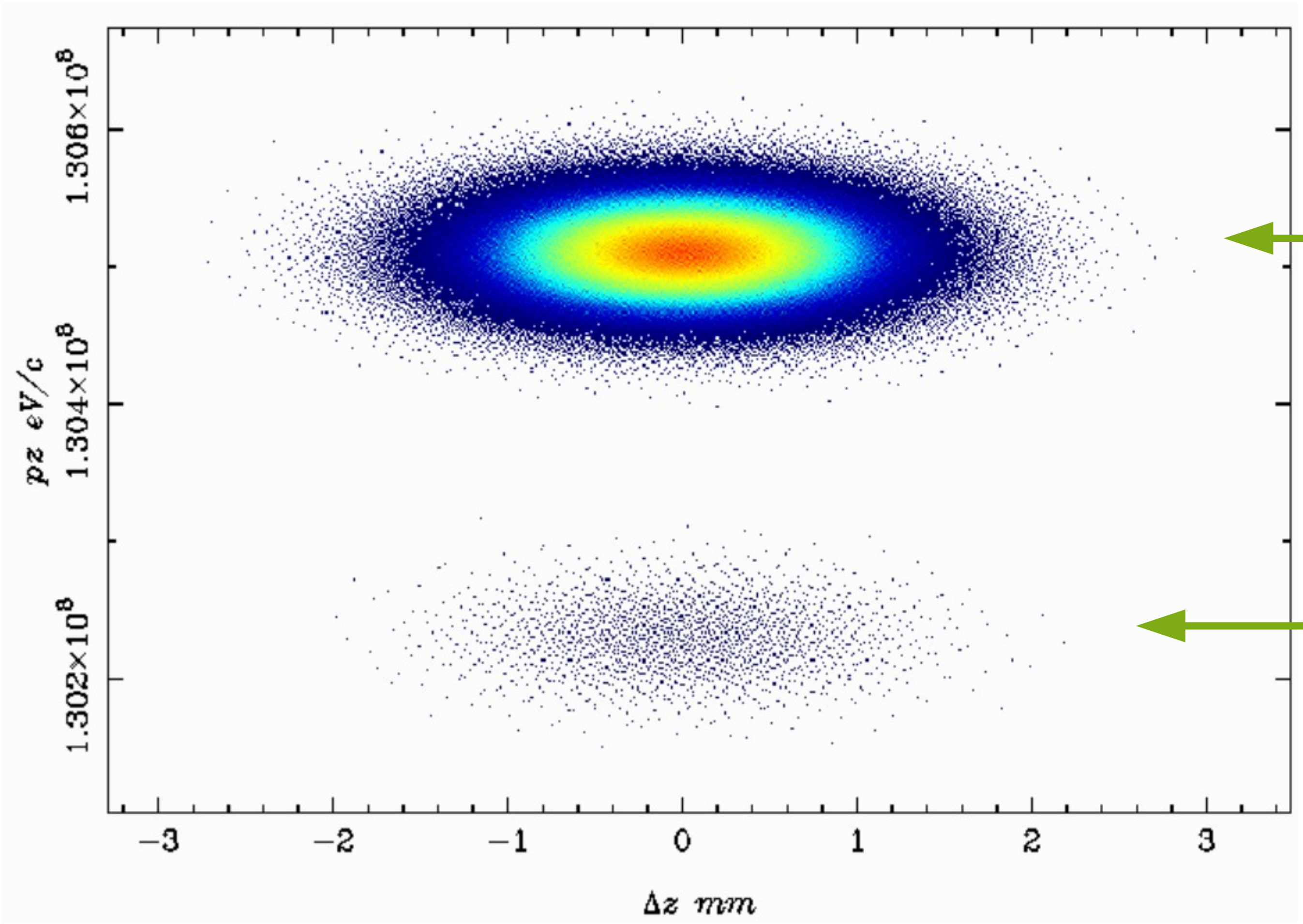
Python calculations for Thomson scattering of 130MeV MESA electron bunch & 566nm Laser at observation angle θ = 1/(3γ)

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



Longitudinal phase space of MESA 130MeV 0.77pC electron bunch after 566nm Thomson scattering

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



$4.8045 \cdot 10^6$ electrons

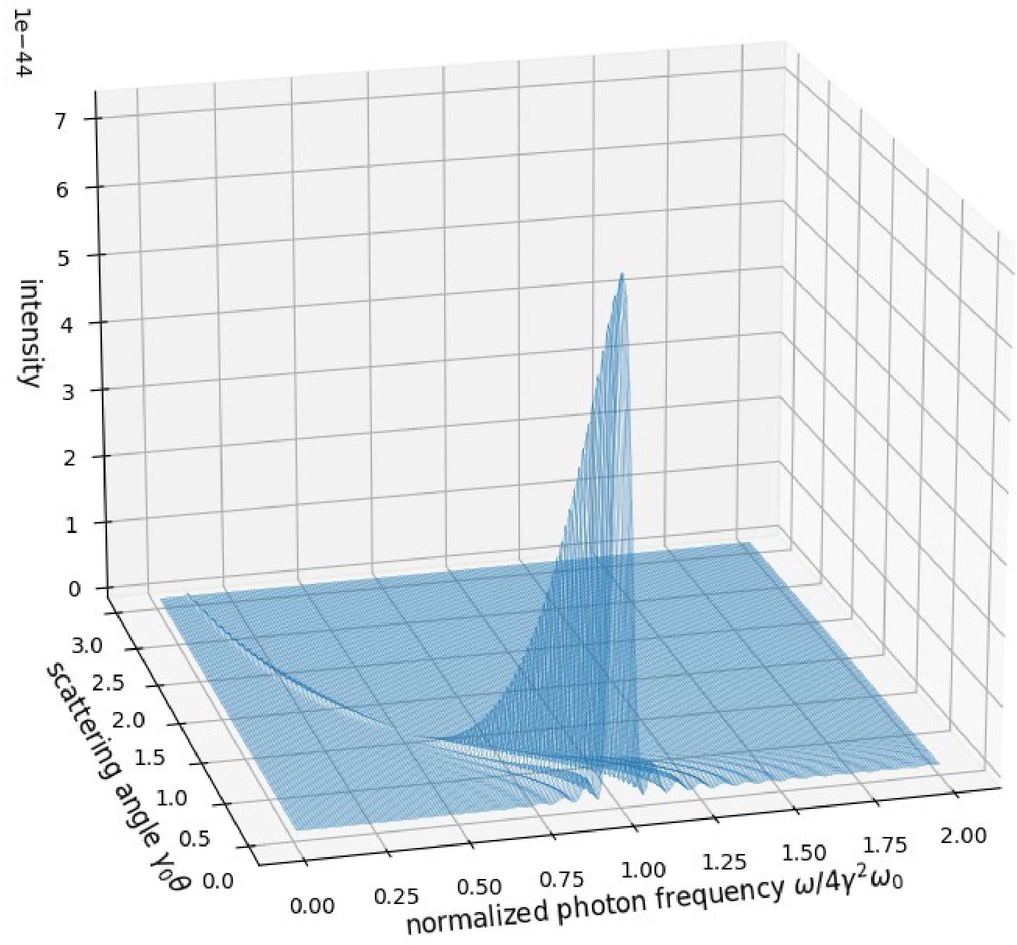
$\bar{E}_e \approx 130.511$ MeV

2k electrons

$\bar{E}_e \approx 130.226$ MeV

ThoBaSCo calculation of normalized scattered photon intensity for 130MeV MESA & 283nm Laser

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



E_e = 130 *MeV*

Q_{bunch} = 0.77 *pC*

σ_e = $1.205 \cdot 10^{-4}$ *m*

mn_e = 2000

linear polarisation

λ = 283 *nm*

E_{ph} ≈ 4.3811 *eV*

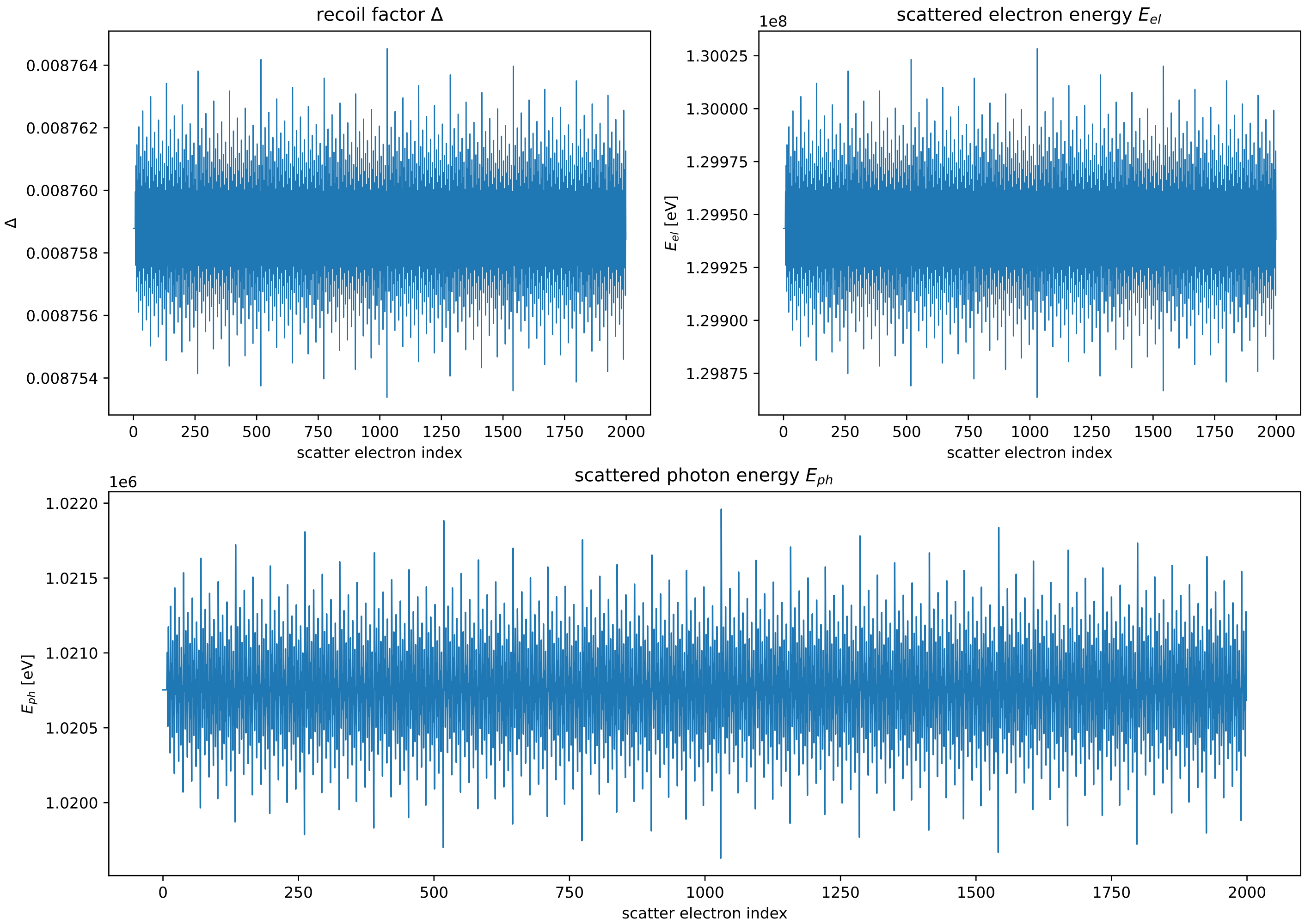
I_0 ≈ $5.7170 \cdot 10^{11}$ *W/cm²*

a_0 ≈ $1.8185 \cdot 10^{-4}$

$4\gamma^2 E_{ph}$ ≈ 1.1431 *MeV*

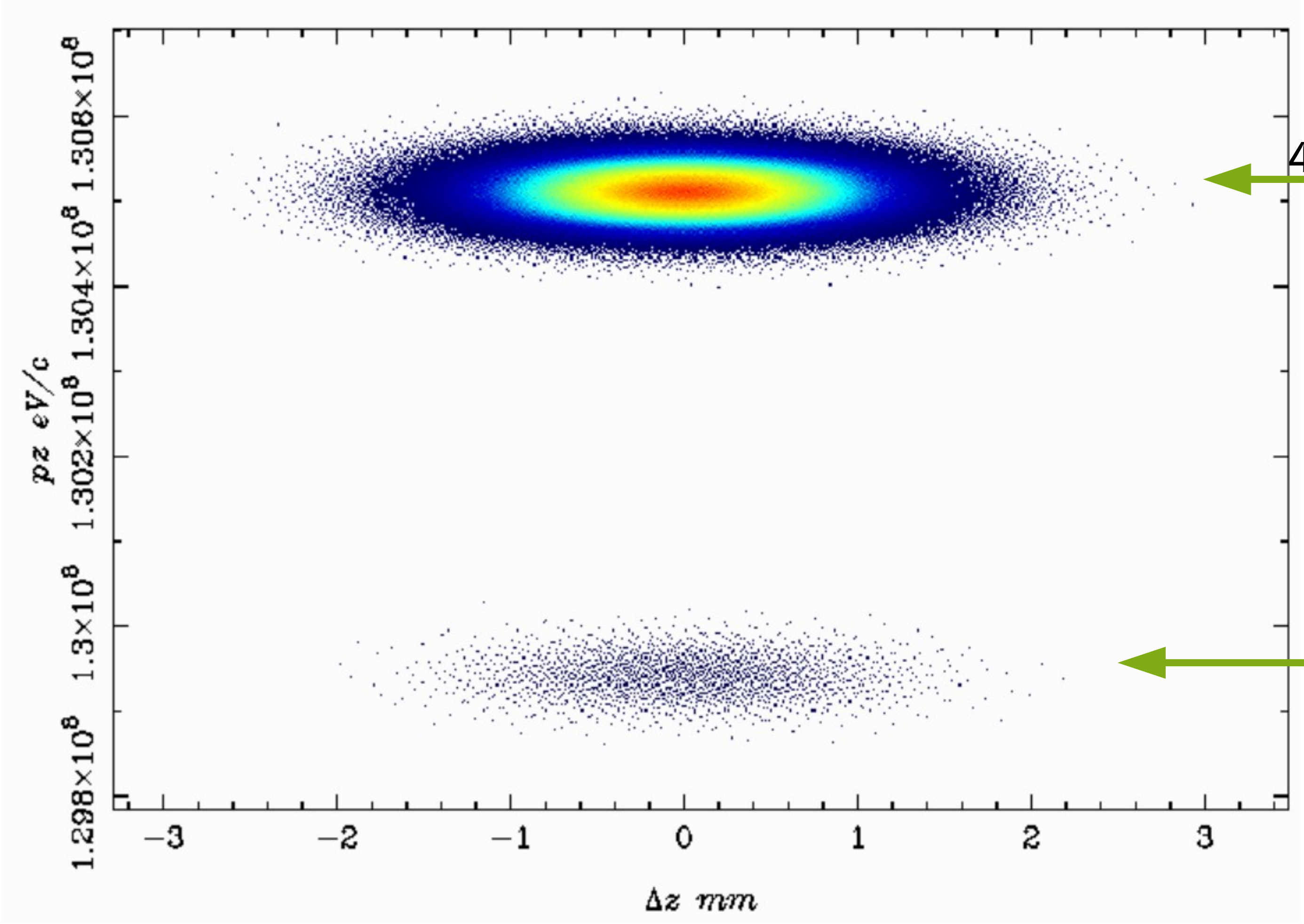
Python calculations for Thomson scattering of 130MeV MESA electron bunch & 283nm Laser at observation angle θ = 1/(3γ)

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



Longitudinal phase space of MESA 130MeV 0.77pC electron bunch after 283nm Thomson scattering

JOHANNES GUTENBERG UNIVERSITÄT MAINZ



$4.8045 \cdot 10^6$ electrons

$\bar{E}_e \approx 130.511$ MeV

2k electrons

$\bar{E}_e \approx 129.943$ MeV

Merit of Thomson scattering at MESA

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

- Thomson scattering with small a_0 results in a per mille of electrons possessing a lower energy. $E_{var} \approx 0.0011 - 0.0044$ for $\lambda = 1132 - 283nm$
- As MESA runs at 1.3GHz, a MHz repetition rate on the electron side is easily achievable while a 1kHz lasers pulse rate is commonly available and can feasibly be multiplied using Fabry-Perot Cavity solutions, both ensuring a high scattered photon flux.
- recovery and transportation of halo particles depends on Thomson scattering arc design as well as MESA energy acceptance
- this constitutes a hard limit of achievable maximum scattered photon energy independent of laser feasibility

Outlook on further work as part of PhD thesis

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

- detailed gamma radiation intensity study
- lattice design for Thomson scattering arc
- investigation into ways to take advantage of beam polarization
- detailed start to end simulation for Thomson scattering source at MESA

ACCELENCE