GF-CMCC

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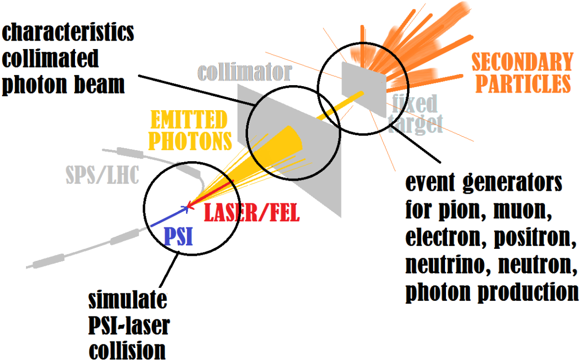
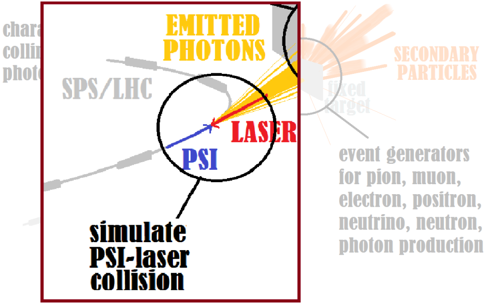

characteristics
collimated
photon beam
collimator
SECONDARY
PARTICLES
fixed
target
EMITTED
PHOTONS
SPS/LHC
LASER/FEL
PSI
event generators
for pion, muon,
electron, positron,
neutrino, neutron,
photon production
simulate
PSI-laser
collision

GAMMA FACTORY: PSI-LASER COLLISION



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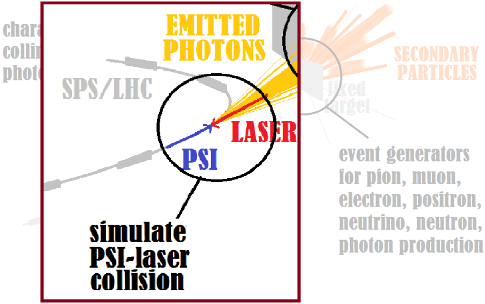

- Laser photon energy in PSI frame $E'_L \simeq 2\gamma E_L$
- Resonance cross section $\sim$ Mbarn (6-7 orders higher ICS off e^-)
- High energy photons emitted by spontaneous emission: isotropic emission
- Max energy of the emitted photons $E_\gamma^{max} = 4\gamma^2 E_L = 2\gamma E'_L$

GF-CMCC

CMCC event generator modified for PSI-Laser collisions: GF-CMCC

v1: Resonant absorption as Compton scattering: no time delay of the emission, no stimulated emission. No collision angle, monochromatic laser.
Total number of photons calculation based on the luminosity formula and total cross section from Bessonov's paper [1].

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Monte Carlo simulation (MC) and calculation based on the luminosity formula (LUM) with total cross section calculated.

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v3: Stimulated emission inserted (excited ion can absorb a second photon and it emits in the same direction as the incoming laser photon - at low energy) for the Monte Carlo simulation (MC).

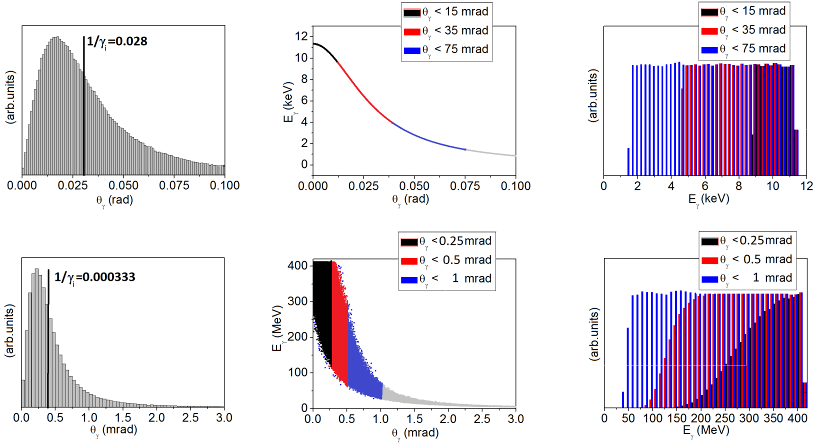
SPS and LHC examples

Two examples for SPS and LHC respectively from Bessonov's paper: Xe^{39+} and Pb^{81+}-laser collisions.

PSI Beam	Xe^{39+}	Pb^{81+}
M_i ion mass	120 GeV/c^2	193 GeV/c^2
E_i ion energy	4.19 TeV	579 TeV
$\gamma_i = E_i/M_i$	34.66	3000
N_i ions per bunch	$2 \cdot 10^9$	$9.4 \cdot 10^7$
$\Delta\gamma_i/\gamma_i$ rel. en. spread	$3 \cdot 10^{-4}$	0
ϵ^n norm. trans. emitt.	2 mm mrad	9 mm mrad
$\beta_x = \beta_y$ beta function	50 m	0.5 m
σ_x rms trans. size	1.7 mm	38.7 μm
σ_z rms bunch length	12 cm	15 cm
Laser	**Green**	**FEL**
λ_L wavelength (E_L photon energy)	532 nm (2.33 eV)	108.28 nm (11.45 eV)
N_L photons per pulse	$8.73 \cdot 10^{14}$	$3 \cdot 10^{13}$
U_L pulse energy	0.33 mJ	56 μJ
P_L mean power (rep. rate 40 MHz)	13.2 kW	2.24 kW
w_0 waist at IP (2 σ_L)	3.4 mm	50.84 μm
R_L Rayleigh length	68.23 m	7.5 cm
σ_t rms pulse length	1 m	15 cm
γ photons		
$E_{res} = E_L'$ resonance energy	161.5 eV	68.7 keV
E_γ^{max} maximum photon energy	11.2 keV	412 MeV

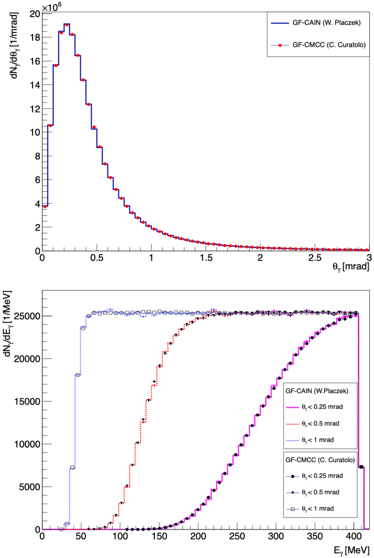
Xe^{39+} AND Pb^{81+}

Features of secondary photons emitted by Xe^{39+}-laser collision first row and Pb^{81+}-FEL second row, simulation with GF-CMCC. First column: angular distribution of full emitted photon beam and $1/\gamma_i$ value reported. Second column: energy as function of the emission angle, colours represent different collimation angles. Third column: energy distribution for three possible collimated beams.



Pb^{81+}

GF-CAIN and GF-CMCC results comparison in Pb^{81+}-FEL collision. Top: angular distribution of full photon beam. Bottom: spectrum of emitted photon beam collimated at $\theta_\gamma = 0.25, 0.5, 1$ mrad. Normalized to GF-CMCC total photons.



Pb^{81+}

Luminosity formula with $\bar{\sigma}$ from Bessonov's [1] gives an OVERESTIMATION of the number of photons per ion:

$$N_\gamma = \frac{N_L}{2\pi(\sigma_x^2 + \sigma_L^2)}\bar{\sigma} = \frac{3 \cdot 10^{13}}{2\pi((38.7 \cdot 10^{-6})^2 + (25.42 \cdot 10^{-6})^2)} 3.32 \cdot 10^{-22} = 0.739$$

GF-CMCC results (to be controlled - very long pulses, laser far from diffraction limited):

laser at resonance

```
---------------------------------------------------------------------------
Cross section (Mbarn)         0.58235900503299087
Photons per ion              MC    8.8930999999999996E-002  LUM  0.13087509924513643
Real photons per shot (10^7) MC  0.83595140000000001        LUM   1.2302259329042824
---------------------------------------------------------------------------
```

laser 2 sigma below resonance

```
---------------------------------------------------------------------------
Cross section (Mbarn)         0.51154185036851507
Photons per ion              MC    7.8283000000000005E-002  LUM  0.11496017036986919
Real photons per shot (10^7) MC  0.73586019999999996        LUM   1.0806256014767706
---------------------------------------------------------------------------
```

POP EXAMPLE

Proof of principle experiment parameters:

```
2000000         !nions ----- num of macroparticles
193.687D+9      !mion ----- ion mass in eV
18.68908D+12    !eionmed  ----- mean ion energy
0.0003          !relenspread ------rel energy spread
0.001051        !sigx ---- in m
0.001171        !sigy ---- in m
0.12            !sigz ----- in m
1.5D-6          !emitt_n
2.D+8           !n_ion ----num ion per bunch
230.76          !rismed ---- resonance energy in eV
0.0051          !U_L energy laser in J
0.00015         !delas relative energy spread laser
2.D-3           !sigl ---- rms transverse size laser in m
3.7D-12         !sigt ----- laser length in s
2.6672D+16      !n_ph ----num laser photons
0               !ncmcut 1=selection in angle in CM/ 0=no sel
74.D-12         !tau0 ---- mean lifetime spont emission in s
6.              !dscreen ---- screen distance in m
1.              !rep -----repetition rate collisione
2.              !g1
2.              !g2
2.              !angcoll in deg
```

POP GF-CMCC V2

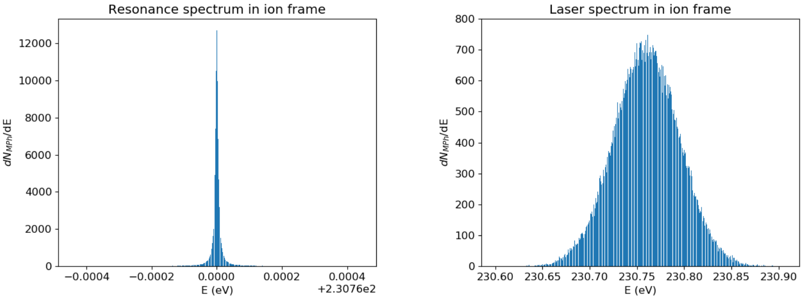
Total cross section, number of emitted photons per ion per shot and real photons per shot in PoP case. Maximum one interaction per ion with laser at resonance, 1 σ below resonance, 2 σ below resonance. Without stimulated emission.

```
----------------------------------------------------------------------
Cross section (Mbarn)          3.3087673668321855
Photons per ion              MC  0.19919350000000000       LUM  0.20177807875131243
Real photons per shot (10^7) MC    3.9838700000000000       LUM    4.0355615750262483
----------------------------------------------------------------------
```

```
----------------------------------------------------------------------
Cross section (Mbarn)          2.9957602550832885
Photons per ion              MC  0.18044900000000000       LUM  0.18269001160907825
Real photons per shot (10^7) MC    3.6089799999999999       LUM    3.6538002321815646
----------------------------------------------------------------------
```

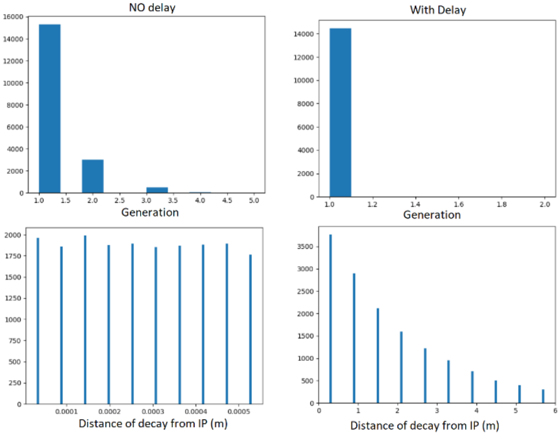
```
----------------------------------------------------------------------
Cross section (Mbarn)          2.2165737618689119
Photons per ion              MC  0.13336750000000000       LUM  0.13517299510903011
Real photons per shot (10^7) MC    2.6673499999999999       LUM    2.7034599021806023
----------------------------------------------------------------------
```

Mean lifetime τ_0 of the ion in the excite state (mean time of the spontaneus emission) quite long: line width of resonance modelled by a lorentian much narrower then the laser bandwidth

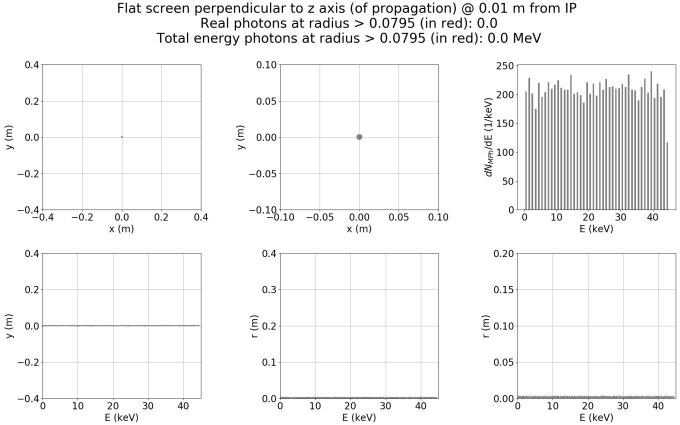


POP GF-CMCC V2: EMISSION TIME DELAY

Big difference without and with time delay (re-emission time). Top row: number of emitted photon generation (1 if the ion interacts only once with the laser, 2 if the ion has already emitted one photon, 3 if the ion has already emitted 2 photons, ...). Bottom row: distance from IP at which the photon is emitted (m).



POP GF-CMCC V2: POP WITH LASER AT RESONANCE



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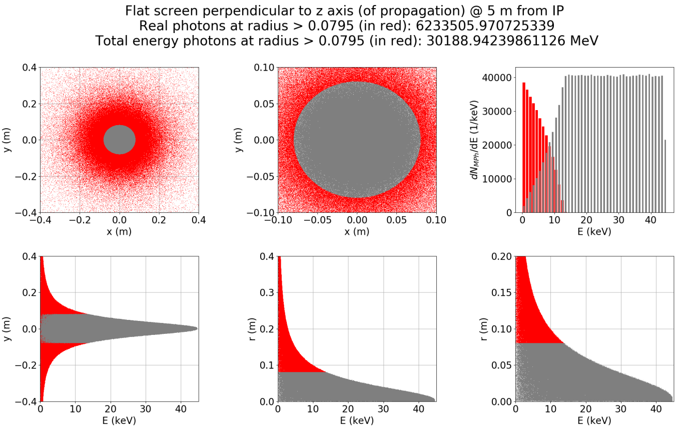

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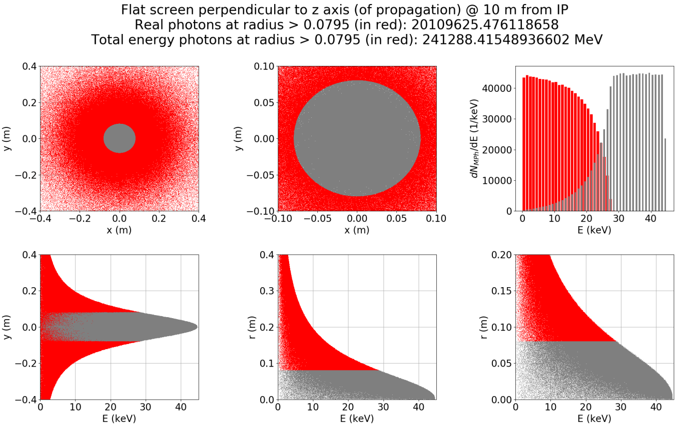
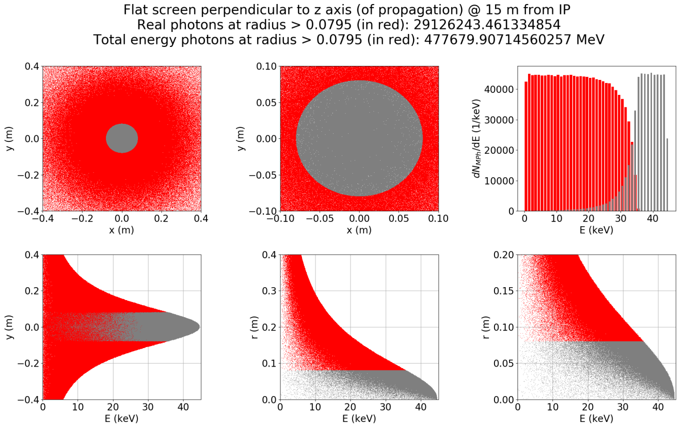


POP GF-CMCC v2: POP with laser at resonance



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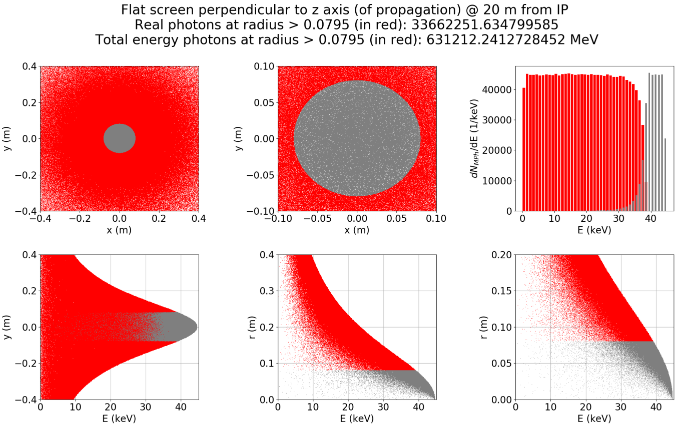
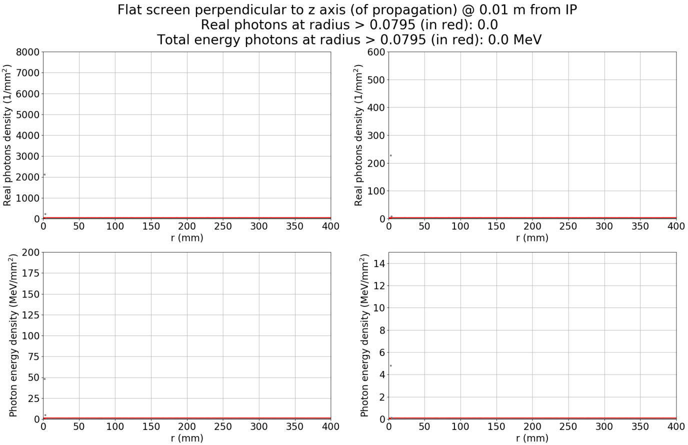
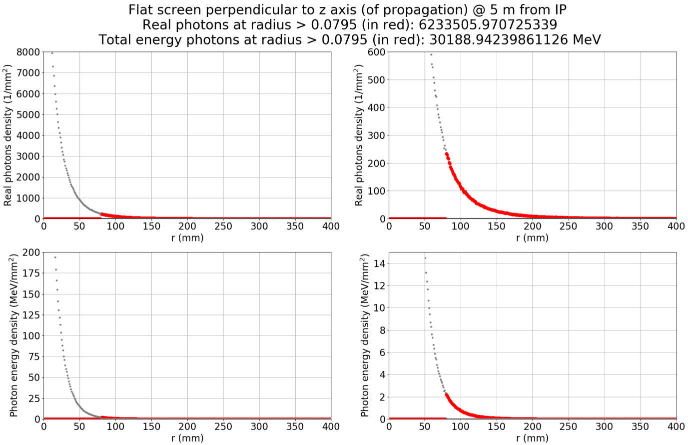


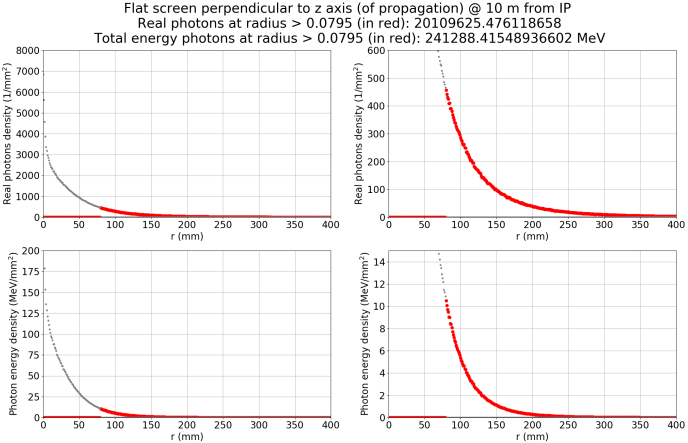
GF-CMCC v2: pop with laser at resonance



GF-CMCC v2: pop with laser at resonance



GF-CMCC v2: pop with laser at resonance



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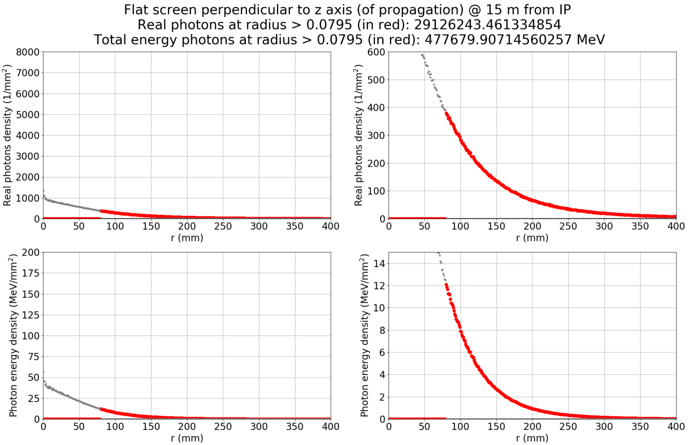
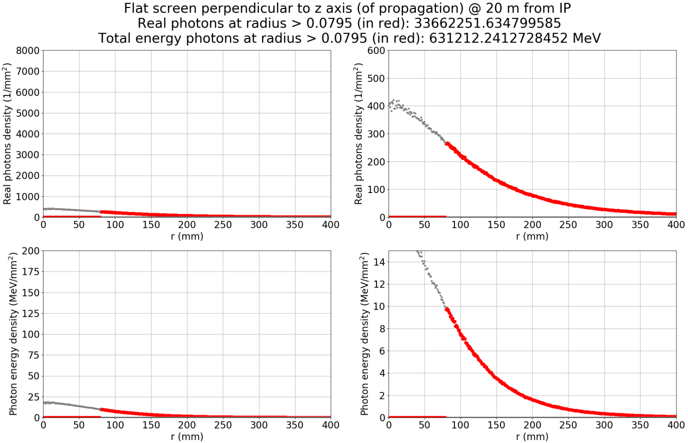
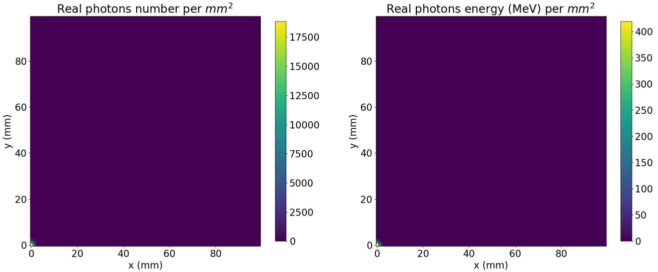


GF-CMCC v2: pop with laser at resonance



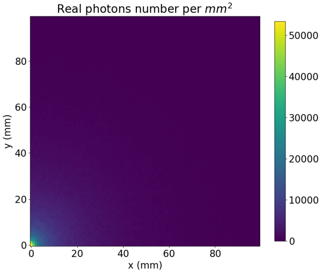
POP GF-CMCC V2: POP WITH LASER AT RESONANCE

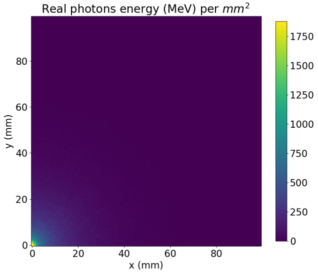
Flat screen perpendicular to z axis (of propagation) @ 0.01 m from IP



POP GF-CMCC V2: POP WITH LASER AT RESONANCE

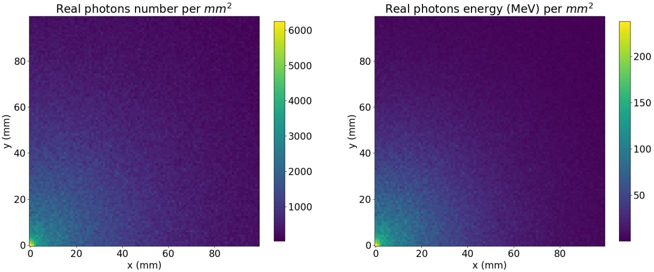
Flat screen perpendicular to z axis (of propagation) @ 5 m from IP





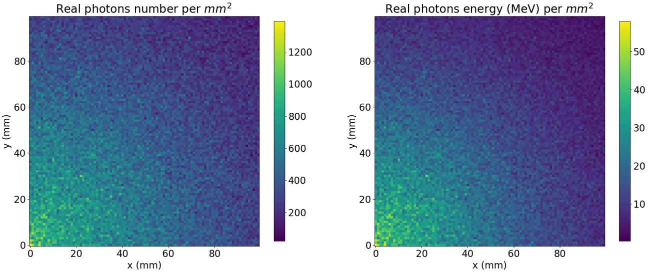
POP GF-CMCC V2: POP WITH LASER AT RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 10 m from IP



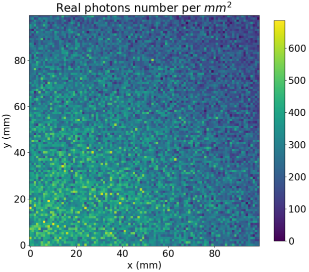
POP GF-CMCC V2: POP WITH LASER AT RESONANCE

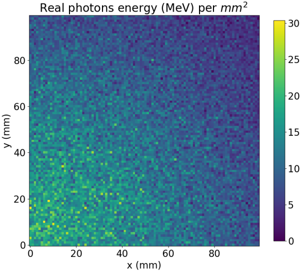
Flat screen perpendicular to z axis (of propagation) @ 15 m from IP



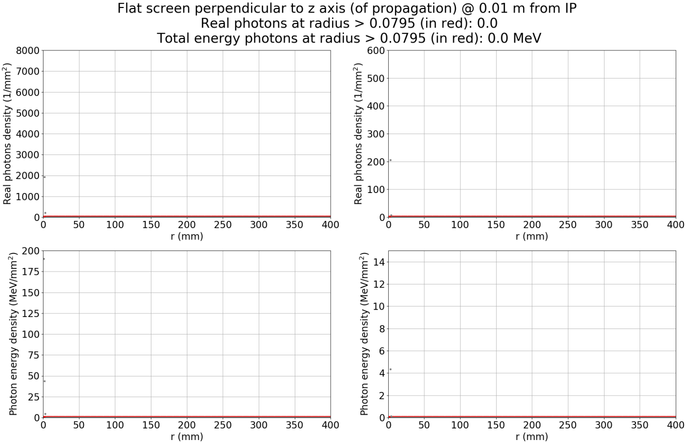
POP GF-CMCC V2: POP WITH LASER AT RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 20 m from IP

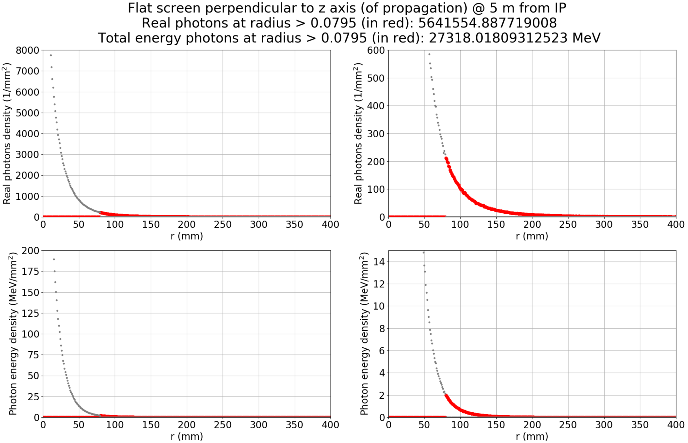




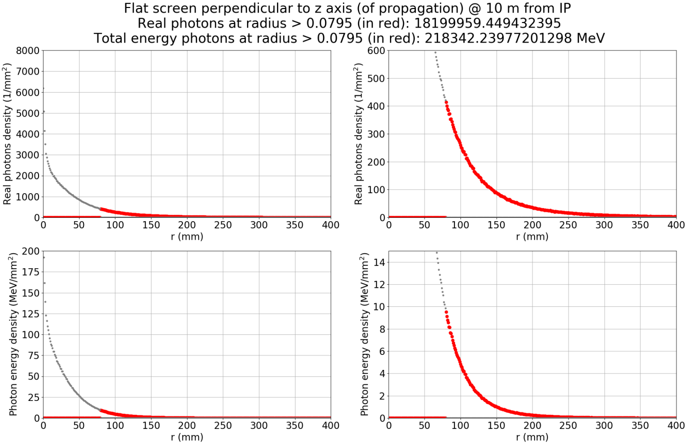
pop gf-cmcc v2: pop with laser 1 σ below resonance



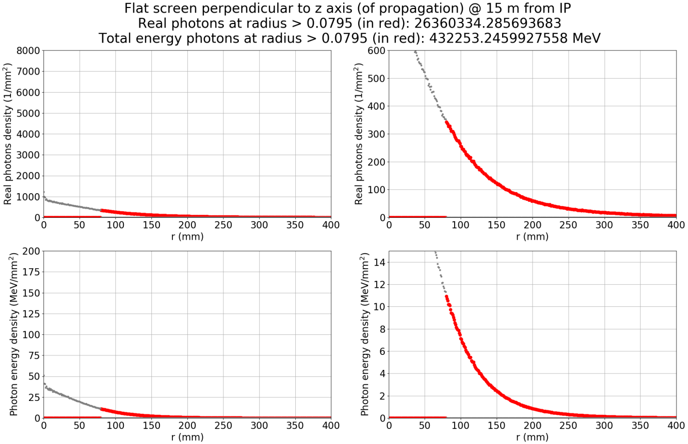
POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE



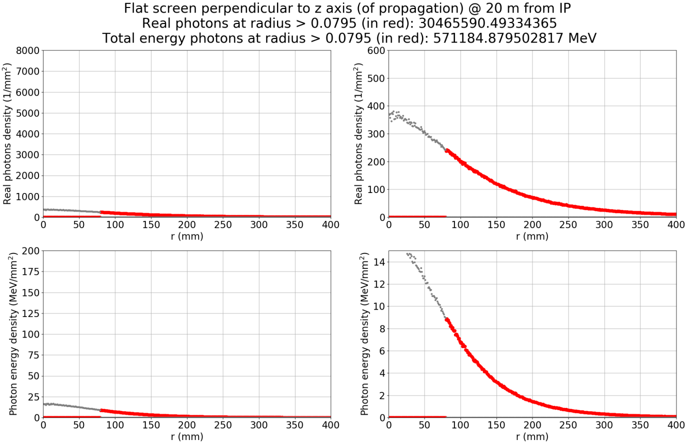
POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE



POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE

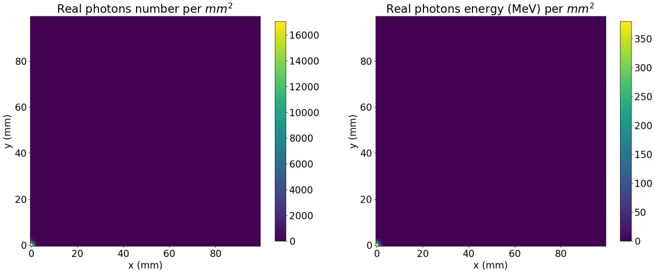


POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE



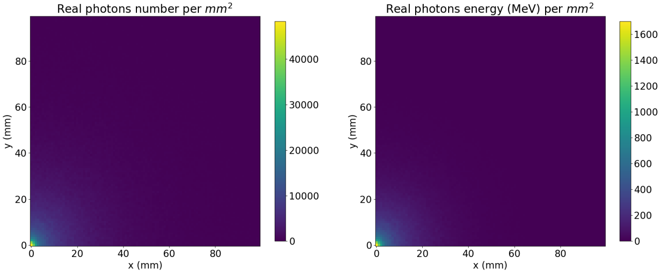
POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 0.01 m from IP



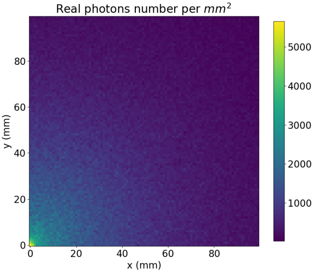
POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 5 m from IP



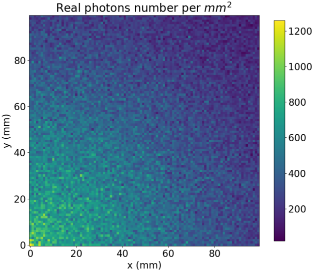
POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE

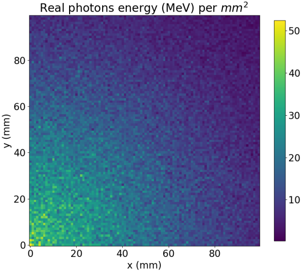
Flat screen perpendicular to z axis (of propagation) @ 10 m from IP



POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE

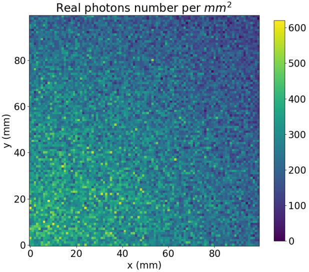
Flat screen perpendicular to z axis (of propagation) @ 15 m from IP

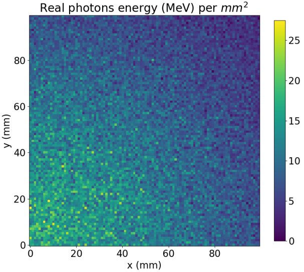




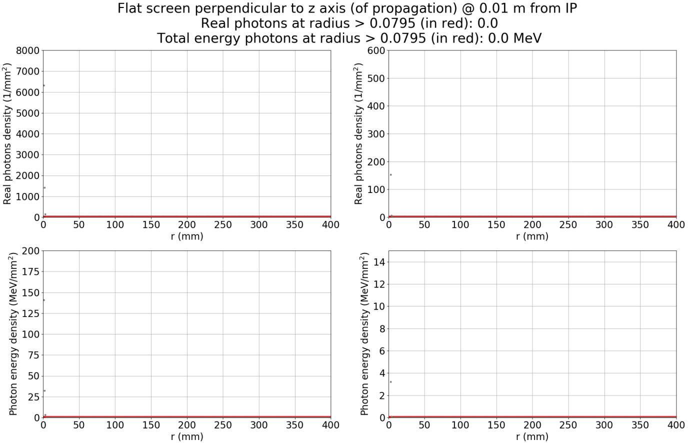
POP GF-CMCC V2: POP WITH LASER 1 σ BELOW RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 20 m from IP

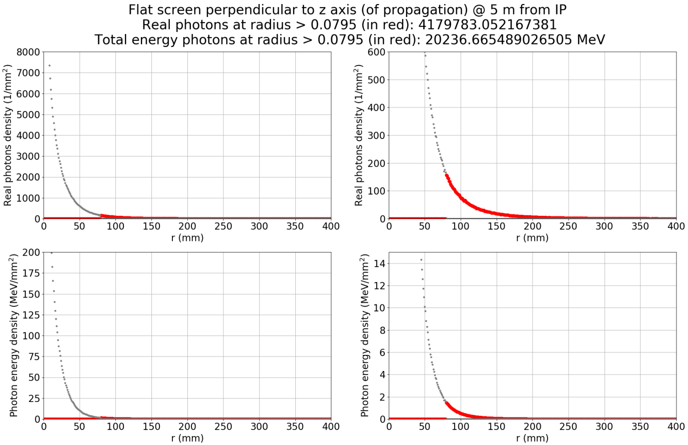




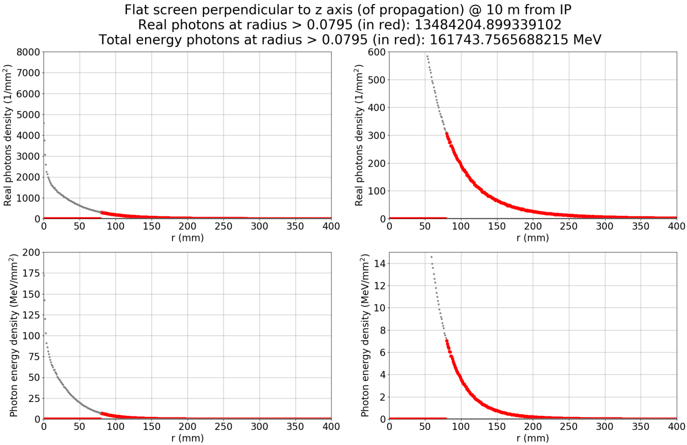
POP GF-CMCC V2: POP WITH LASER 2 σ BELOW RESONANCE



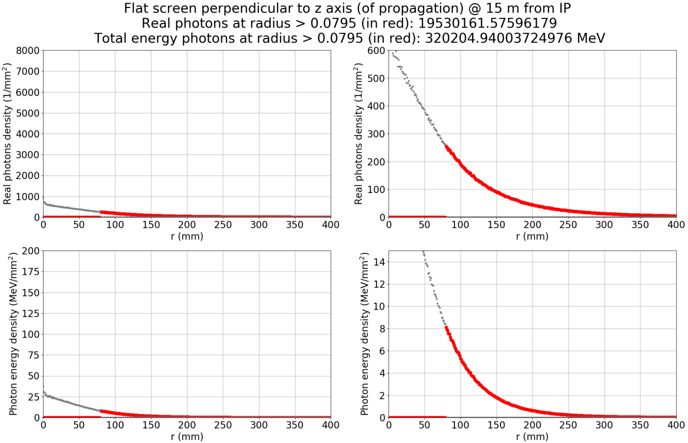
POP GF-CMCC V2: POP WITH LASER 2 σ BELOW RESONANCE



POP GF-CMCC v2: POP with laser 2 σ below resonance

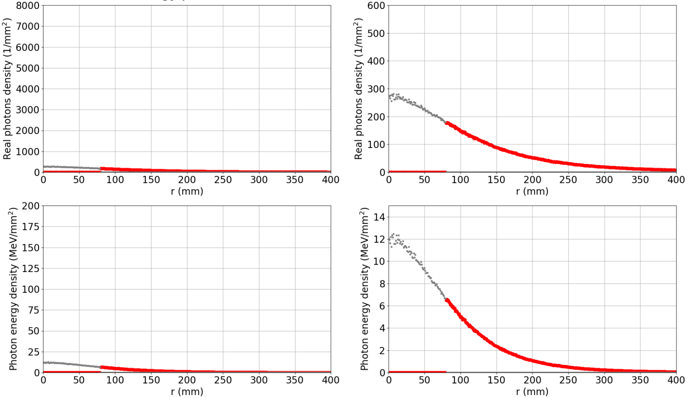


POP GF-CMCC V2: POP WITH LASER 2 σ BELOW RESONANCE



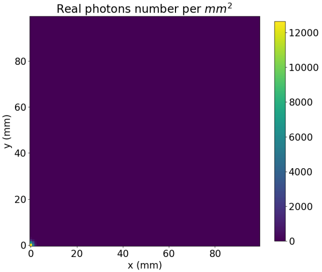
POP GF-CMCC V2: POP WITH LASER 2 σ BELOW RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 20 m from IP
Real photons at radius > 0.0795 (in red): 22571713.180625524
Total energy photons at radius > 0.0795 (in red): 423122.83780234854 MeV



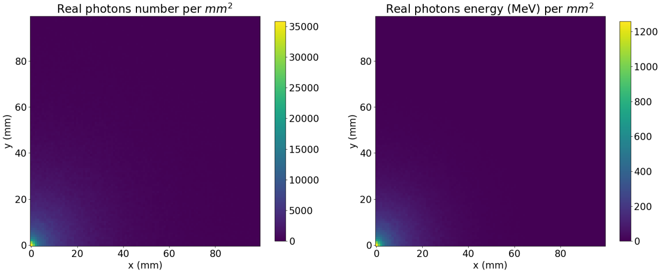
POP GF-CMCC V2: POP WITH LASER 2 σ BELOW RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 0.01 m from IP



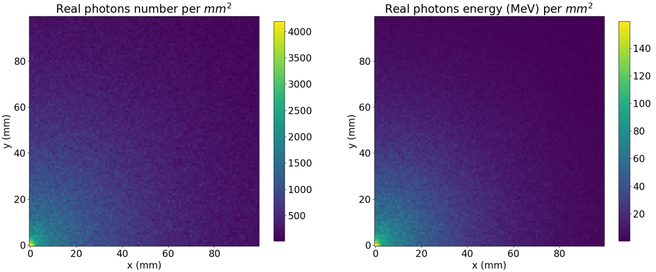
POP GF-CMCC V2: POP WITH LASER 2 σ BELOW RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 5 m from IP



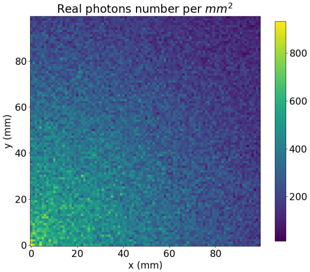
POP GF-CMCC V2: POP WITH LASER 2 σ BELOW RESONANCE

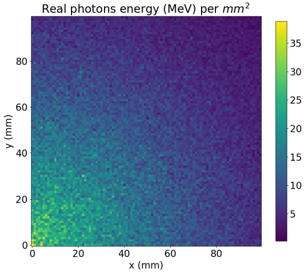
Flat screen perpendicular to z axis (of propagation) @ 10 m from IP



POP GF-CMCC v2: POP with laser 2 σ below resonance

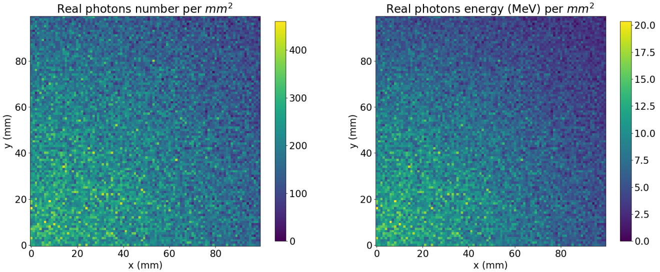
Flat screen perpendicular to z axis (of propagation) @ 15 m from IP





POP GF-CMCC V2: POP WITH LASER 2 σ BELOW RESONANCE

Flat screen perpendicular to z axis (of propagation) @ 20 m from IP



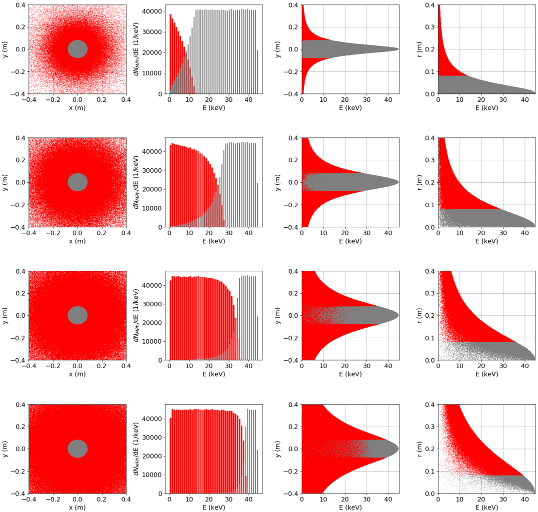
POP GF-CMCC V3

PoP case simualted by GF-CMCC v3 (with stimulated emission):

Code	GF-CMCC	
Simulation method	MC	LUM
N_γ per ion laser at resonance	0.199	0.201
with stimulated emission	0.137	
N_γ per ion laser 1 σ below resonance	0.180	0.182
with stimulated emission	0.124	
N_γ per ion laser 2 σ below resonance	0.133	0.135
with stimulated emission	0.093	

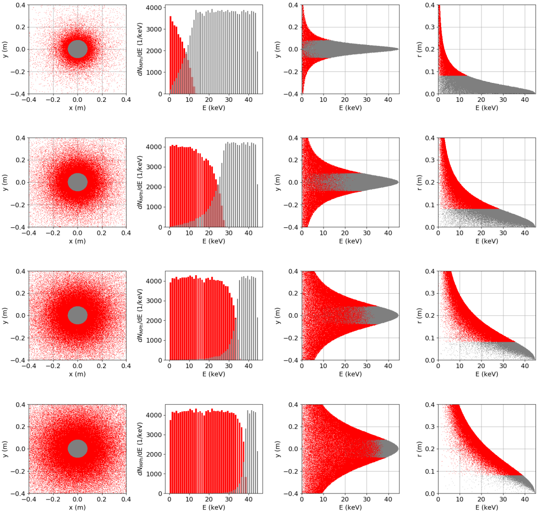
POP GF-CMCC V3: NO STIMULATED EMISSION

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP.



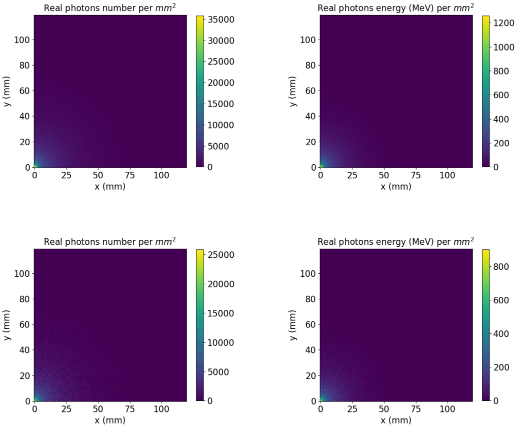
POP GF-CMCC V3: WITH STIMULATED EMISSION

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP.

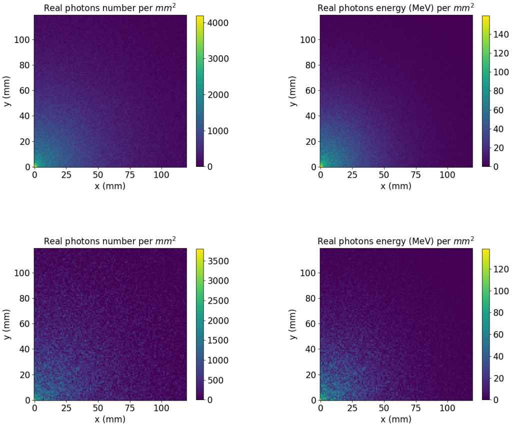


POP GF-CMCC V3: STIMULATED EMISSION EFFECT

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP without (top) and with (bottom) stimulated emission.

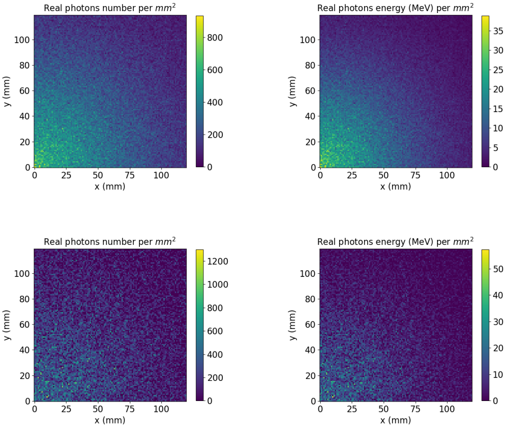


Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP without (top) and with (bottom) stimulated emission.



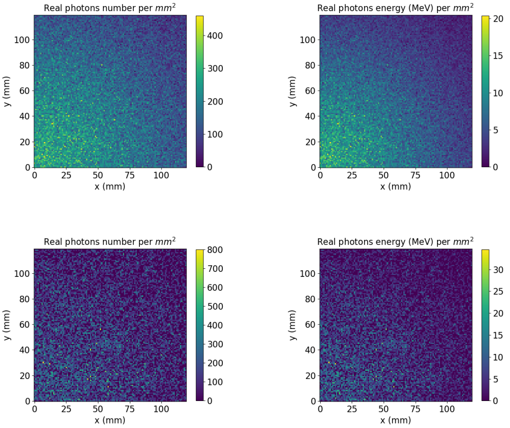
POP GF-CMCC V3: STIMULATED EMISSION EFFECT

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP without (top) and with (bottom) stimulated emission.



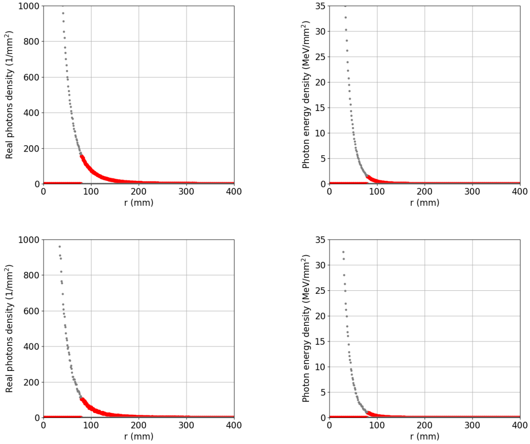
POP GF-CMCC v3: stimulated emission effect

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP without (top) and with (bottom) stimulated emission.



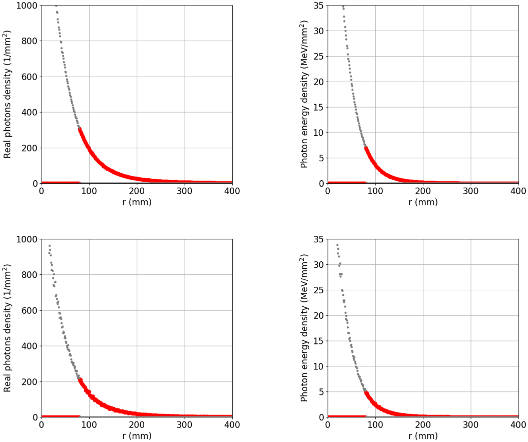
POP GF-CMCC V3: STIMULATED EMISSION EFFECT

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP without (top) and with (bottom) stimulated emission.



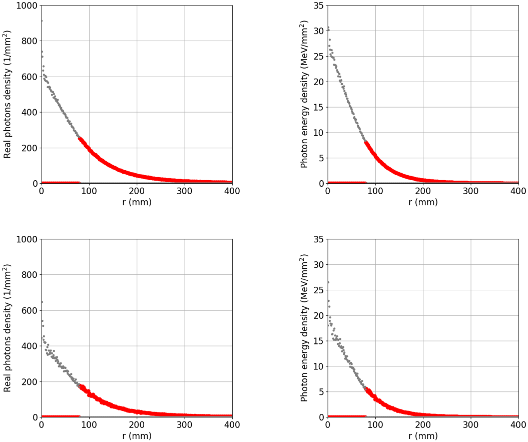
POP GF-CMCC V3: STIMULATED EMISSION EFFECT

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP without (top) and with (bottom) stimulated emission.



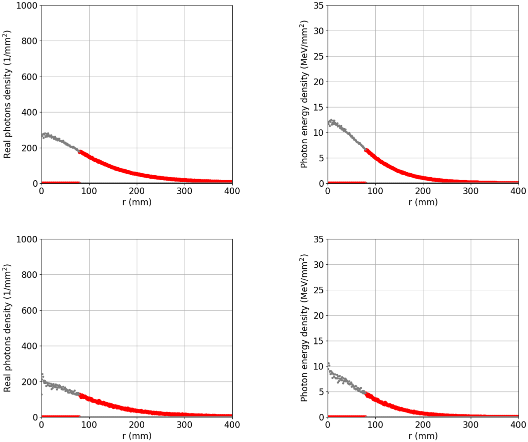
POP GF-CMCC V3: STIMULATED EMISSION EFFECT

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP without (top) and with (bottom) stimulated emission.

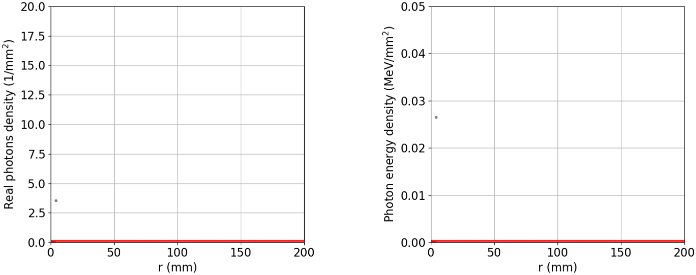


POP GF-CMCC V3: STIMULATED EMISSION EFFECT

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 5, 10, 15, 20 m from IP without (top) and with (bottom) stimulated emission.

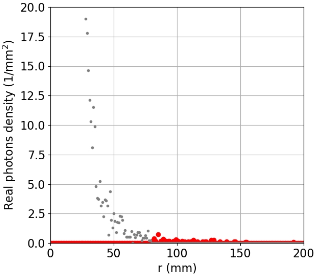


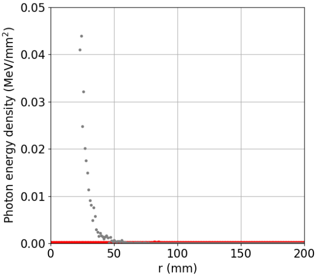
Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 0.01, 0.5, 1, 1.5, 2 m from IP with stimulated emission.



POP GF-CMCC V3: CLOSE TO IP

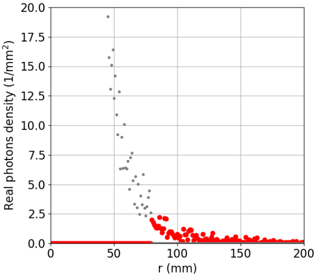
Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 0.01, 0.5, 1, 1.5, 2 m from IP with stimulated emission.

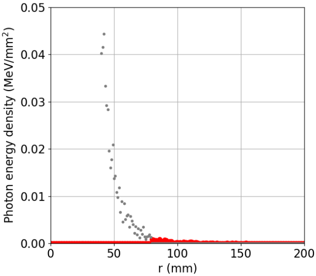




POP GF-CMCC V3: CLOSE TO IP

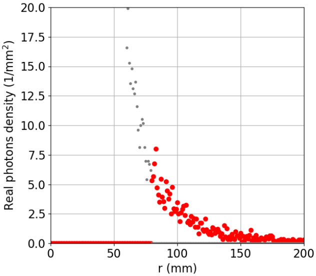
Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 0.01, 0.5, 1, 1.5, 2 m from IP with stimulated emission.

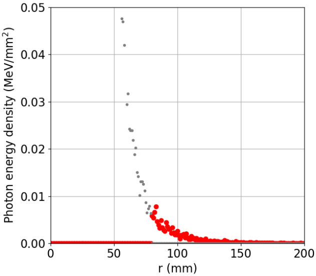




POP GF-CMCC V3: CLOSE TO IP

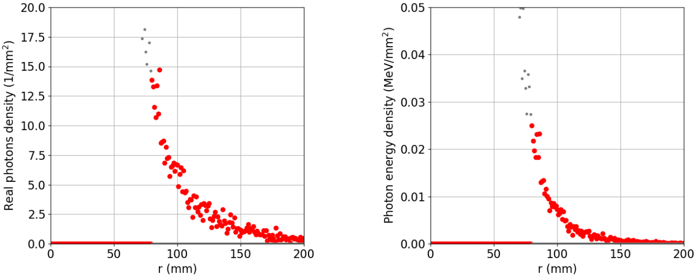
Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 0.01, 0.5, 1, 1.5, 2 m from IP with stimulated emission.





POP GF-CMCC V3: CLOSE TO IP

Laser 2 σ below resonance, emitted photons features on a screen perpendicular to z axis @ 0.01, 0.5, 1, 1.5, 2 m from IP with stimulated emission.



CONCLUSIONS

- Benchmark accurately GF-CMCC with the other codes: validate reliability range
- Perform a complete optimization to define input parameters for PoP
- Generation of stimulated emitted photons

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  - Perform a complete optimization to define input parameters for PoP
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Thank you for your attention!

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- E. G. Bessonov, *Light sources based on relativistic ion beams*, Nucl. Instr. Meth. Phys. Res. B 309 (2013) 92–94
- M. W. Krasny, *The Gamma Factory proposal for CERN*, arxiv:1511.07794 (2015)
- M. W. Krasny *et al.*, *The CERN Gamma Factory initiative: an ultra-high intensity gamma source* in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, BC, Canada, WEYGBD3 (2018)
- C. Curatolo, W. Placzek, L. Serafini, and M. W. Krasny, *New simulation programs for partially stripped ions - laser light collisions* in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, BC, Canada, THPMF076 (2018)